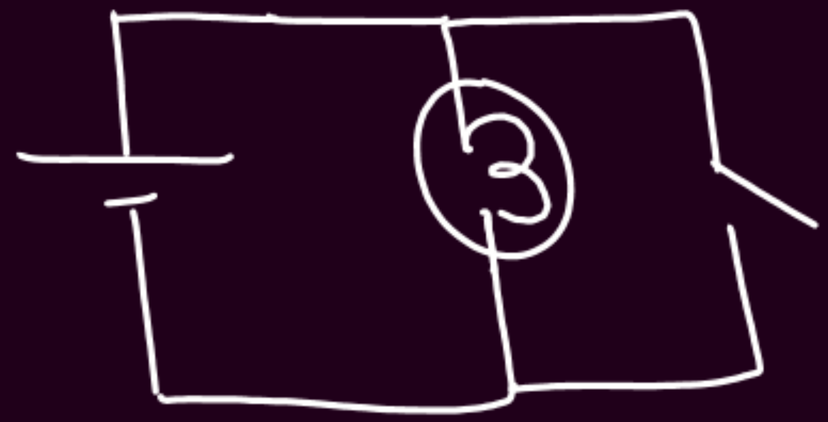
Semi-conductor

Logic Gates

① NOT Gate

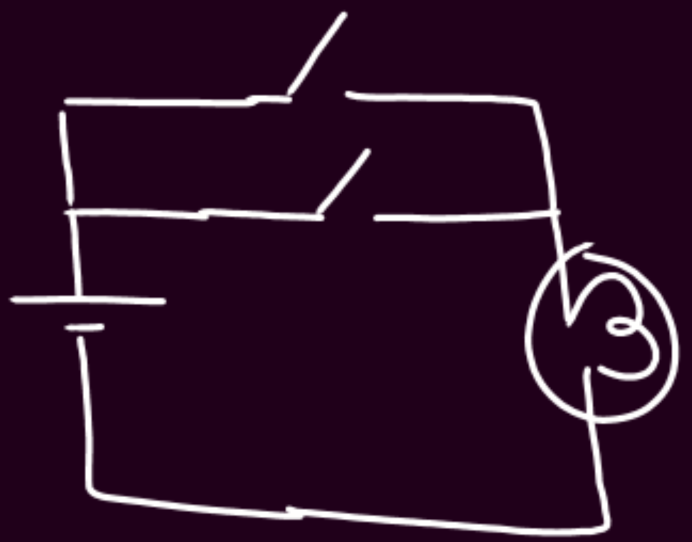
Truth Table

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



② OR Gate

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



③ AND Gate

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

④ NOR Gate

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

⑤ NAND Gate

A	B	$\overline{A.B}$
0	0	1
0	1	1
1	0	1
1	1	0

⑥ XOR → Exclusive OR

$Y = A.\overline{B} + \overline{A}.B$

(Boolean Expression)

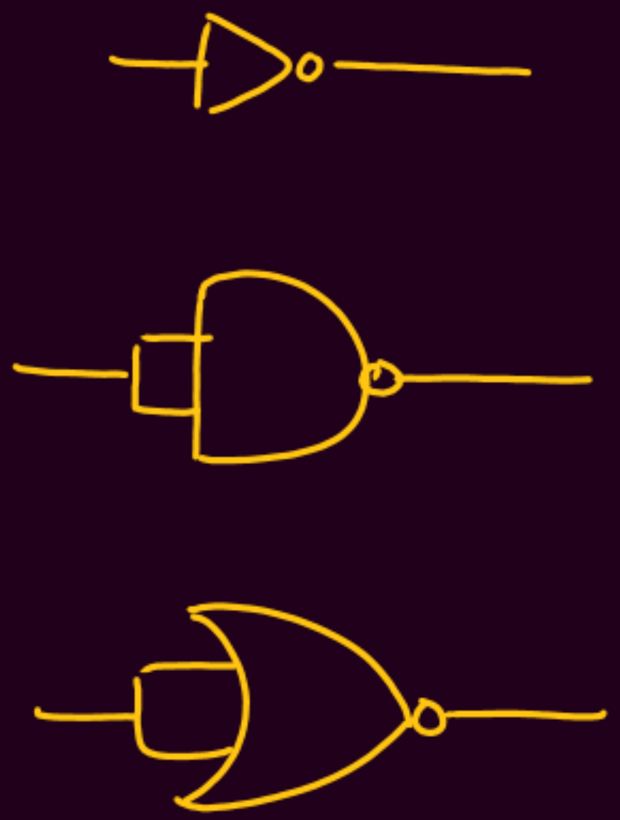
A	B	XOR
0	0	0
0	1	1
1	0	1
1	1	0

⑦ XNOR

$A.B + \overline{A}.\overline{B}$

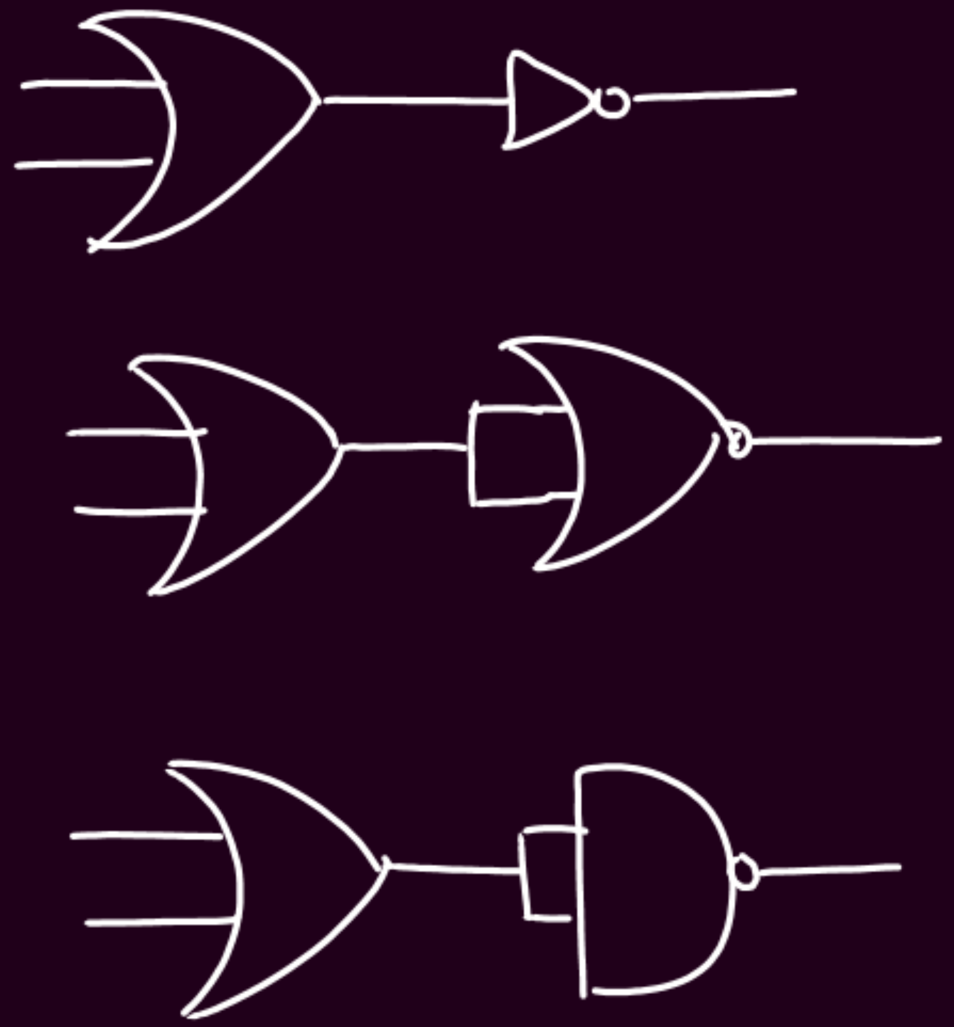
A	B	XNOR
0	0	1
0	1	0
1	0	0
1	1	1

1

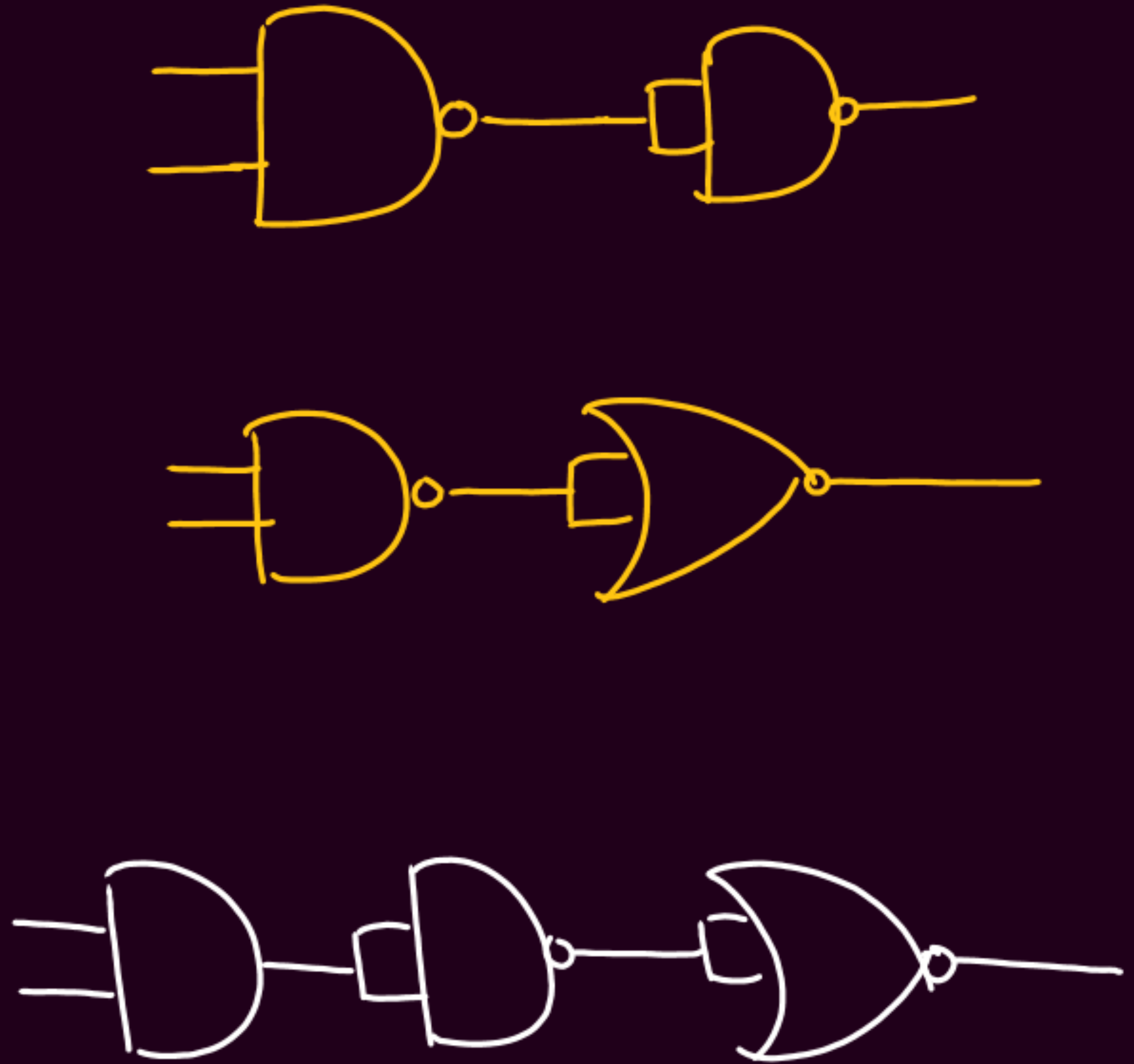


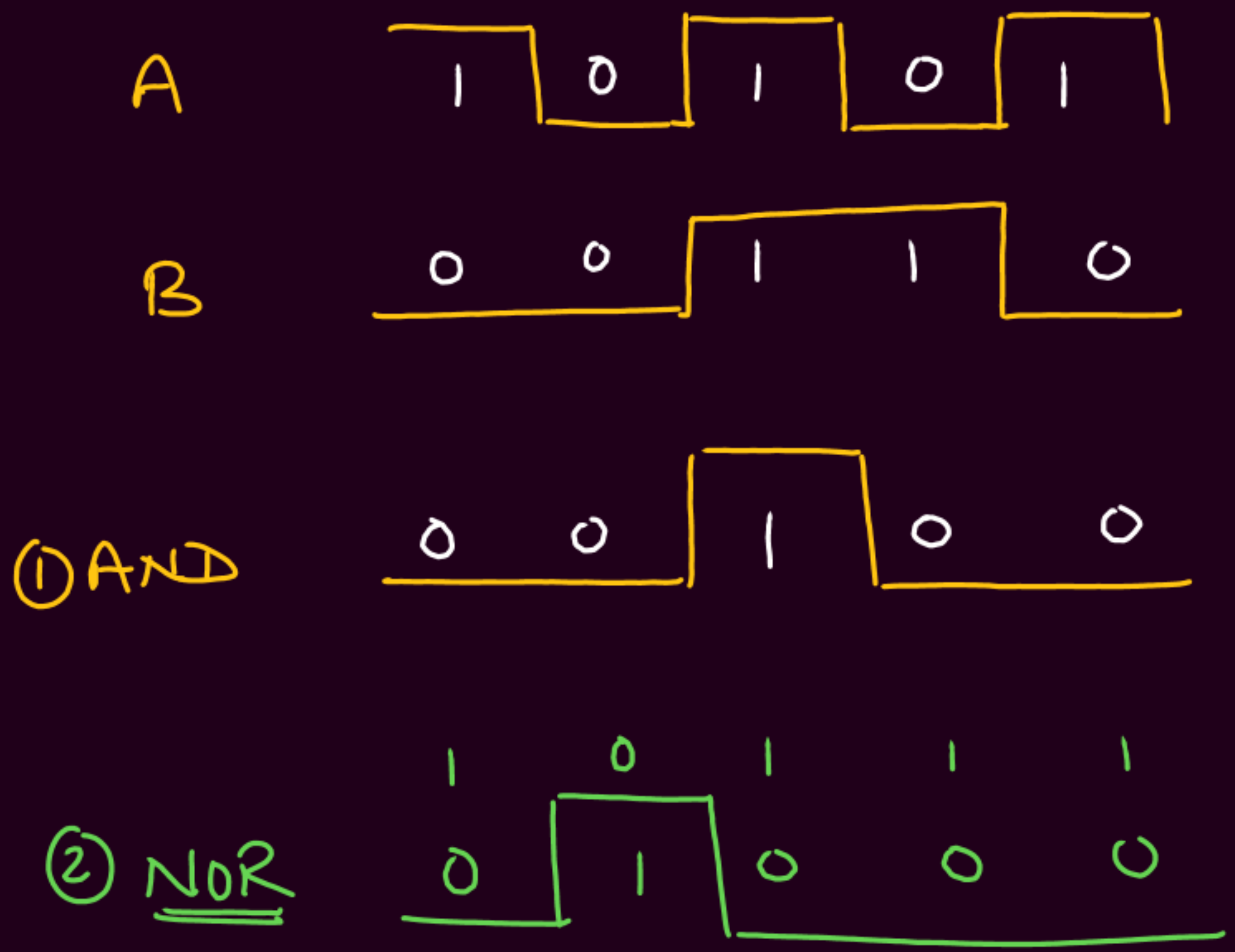
NOT

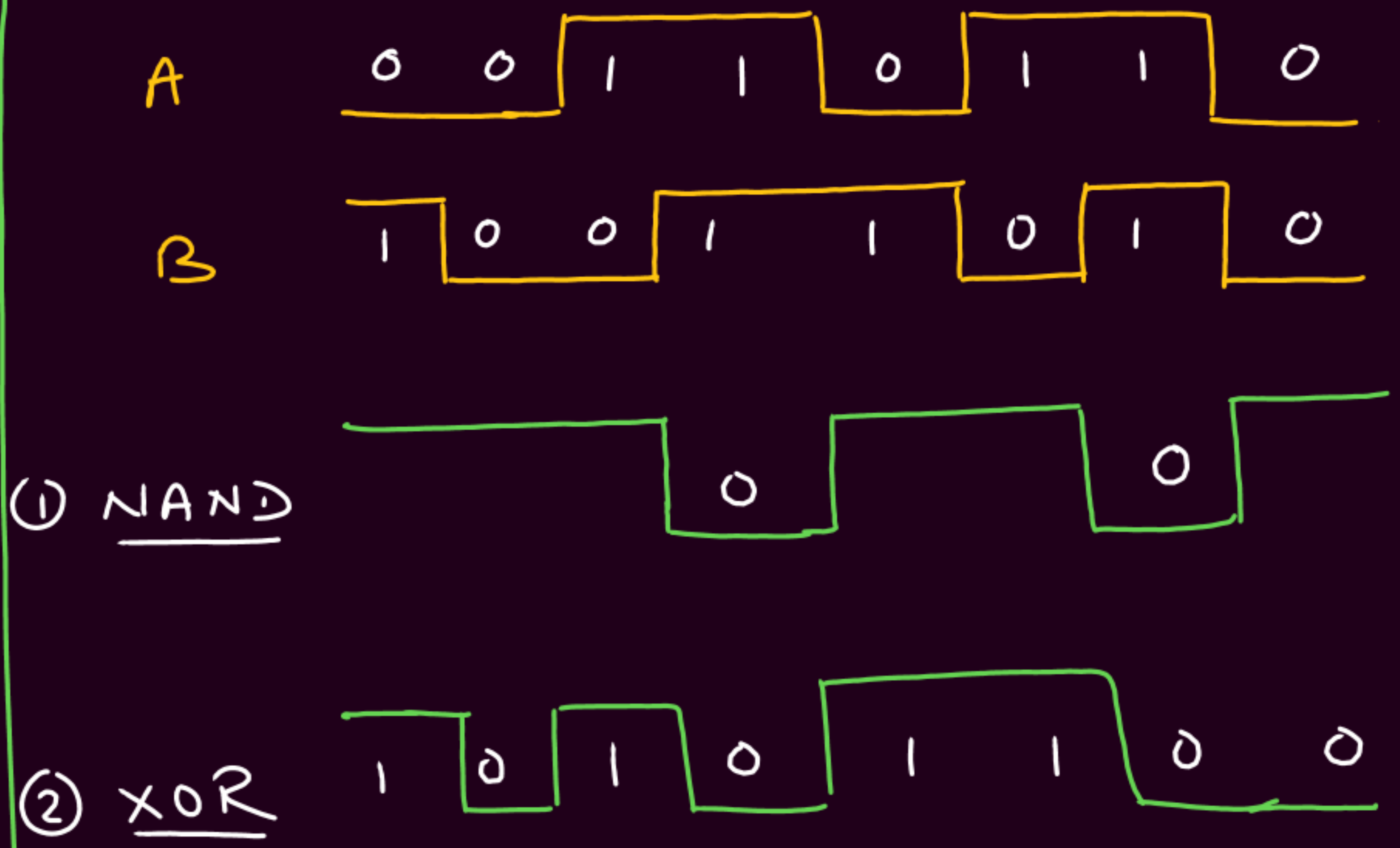
NOR



AND




A 1 0 1 0 1
B 0 0 1 1 0
① AND 0 0 1 0 0
1 0 1 1 1
② NOR 0 1 0 0 0


A 0 0 1 1 0 1 1 0
B 1 0 0 1 1 0 1 0
① NAND 0 0
② XOR 1 0 1 0 1 1 0 0

Boolean Algebra

$A . A = A$

$A . \overline{A} = 0$

$A . 0 = 0$

$A . 1 = A$

$A + A = A$

$A + \overline{A} = 1$

$A + 0 = A$

$A + 1 = 1$

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

② $\overline{A . B} = \overline{A} + \overline{B}$

③ $A + AB = A$

$A(1 + B) = A$

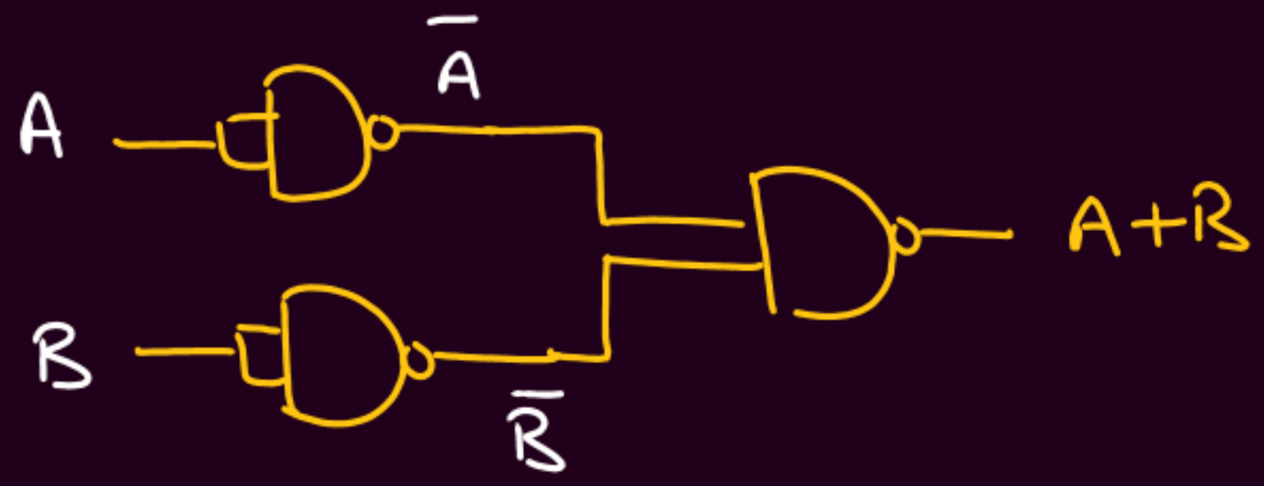
$\overline{\overline{A} + \overline{B}} = \overline{\overline{A}} . \overline{\overline{B}} = A . B$

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

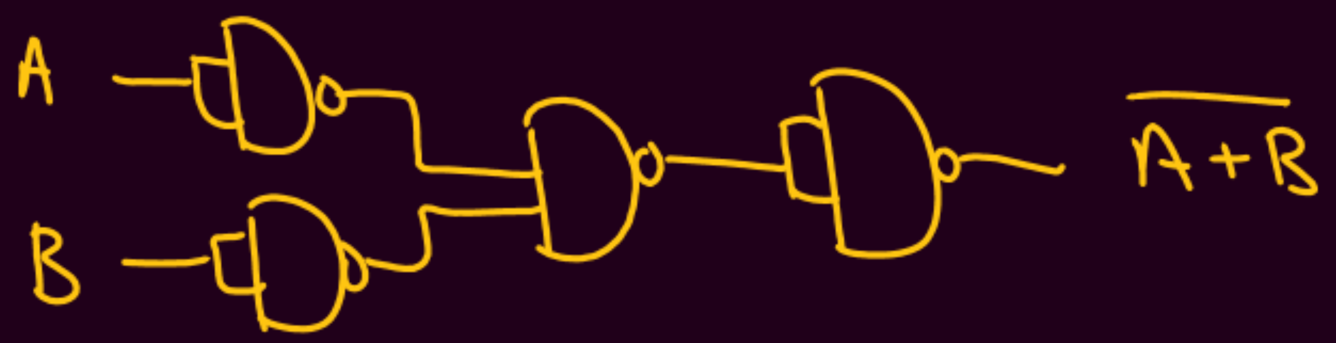
1. NOT

2. AND

3. OR $\overline{\bar{A} \cdot \bar{B}} = A + B$



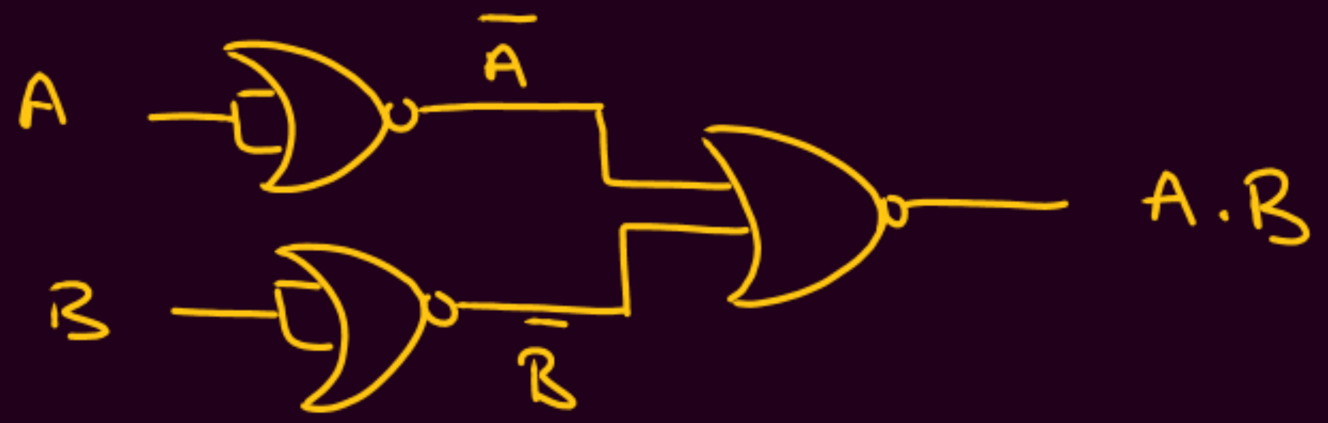
4. NOR



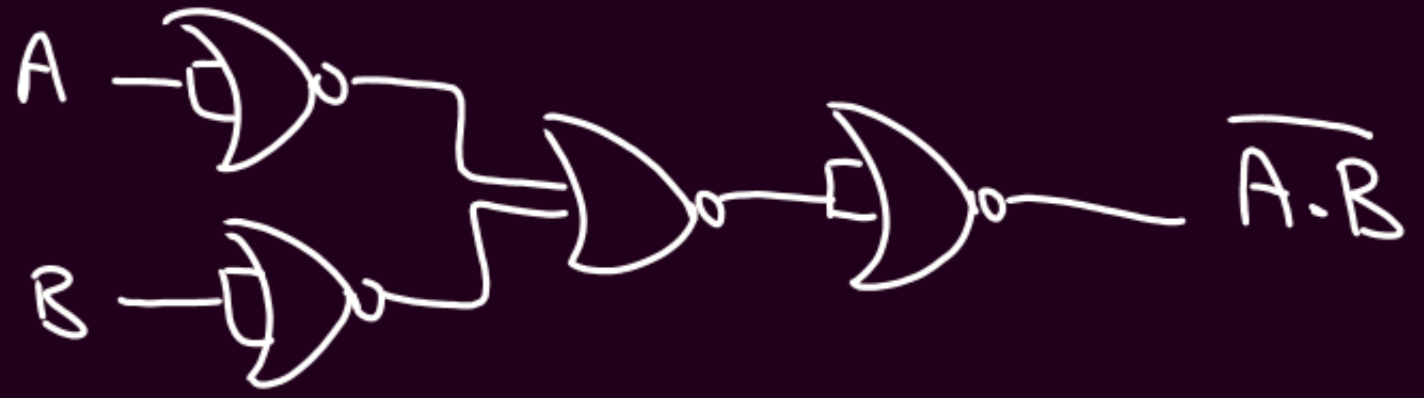
1. NOT

2. OR

3. AND $\overline{\bar{A}+\bar{B}} = A.B$



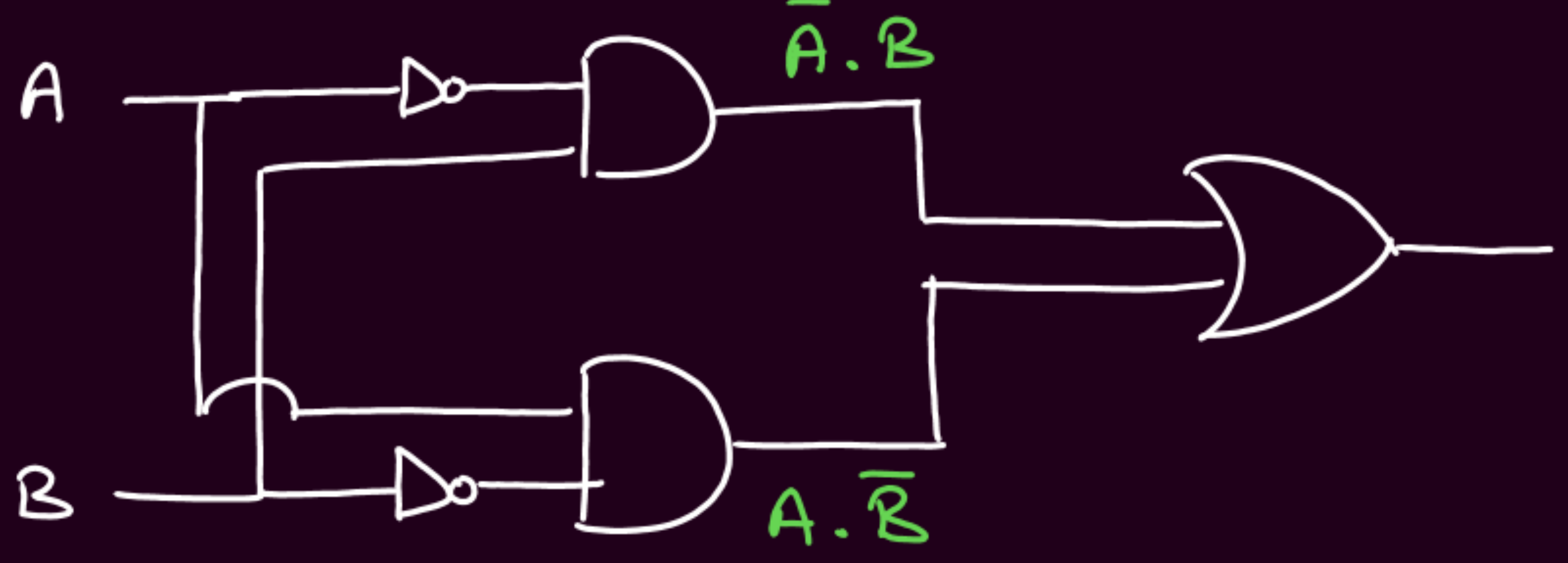
4. NAND



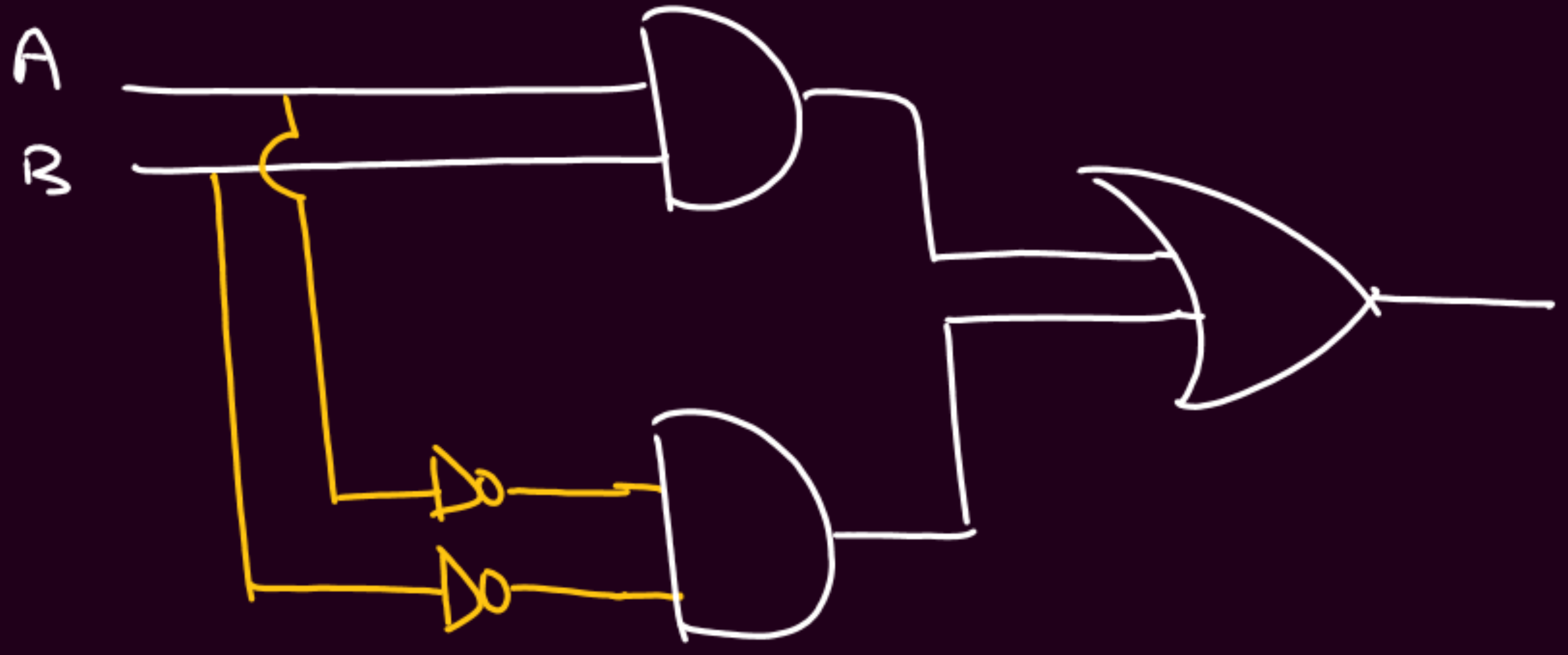
Min no. of Gates Req. to make

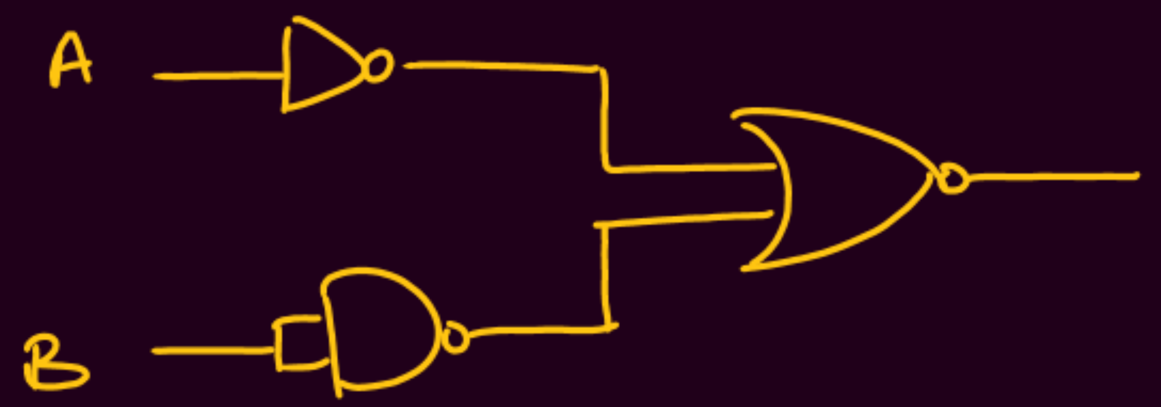
1	NOT using	NOR	1
2	—— " ——	NAND	1
3	OR using	NOR	2
4	AND using	NAND	2
5	AND using	NOR	3
6	NAND —— " ——		4
7	OR using	NAND	3
8	NOR —— " ——		4

XOR $\bar{A}\cdot B + A\cdot\bar{B}$

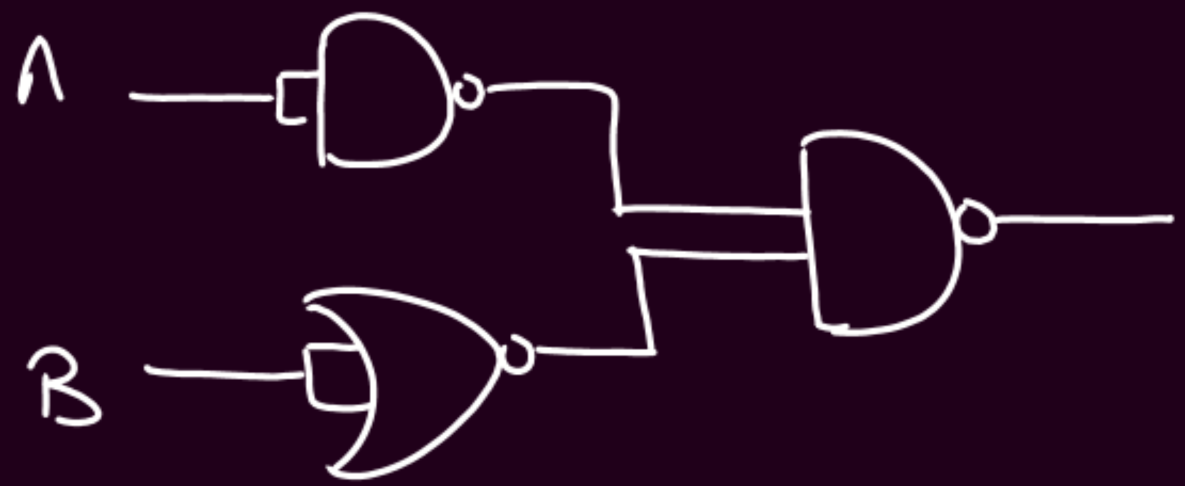


XNOR $A\cdot B + \bar{A}\cdot\bar{B}$ $\overline{A+B}$

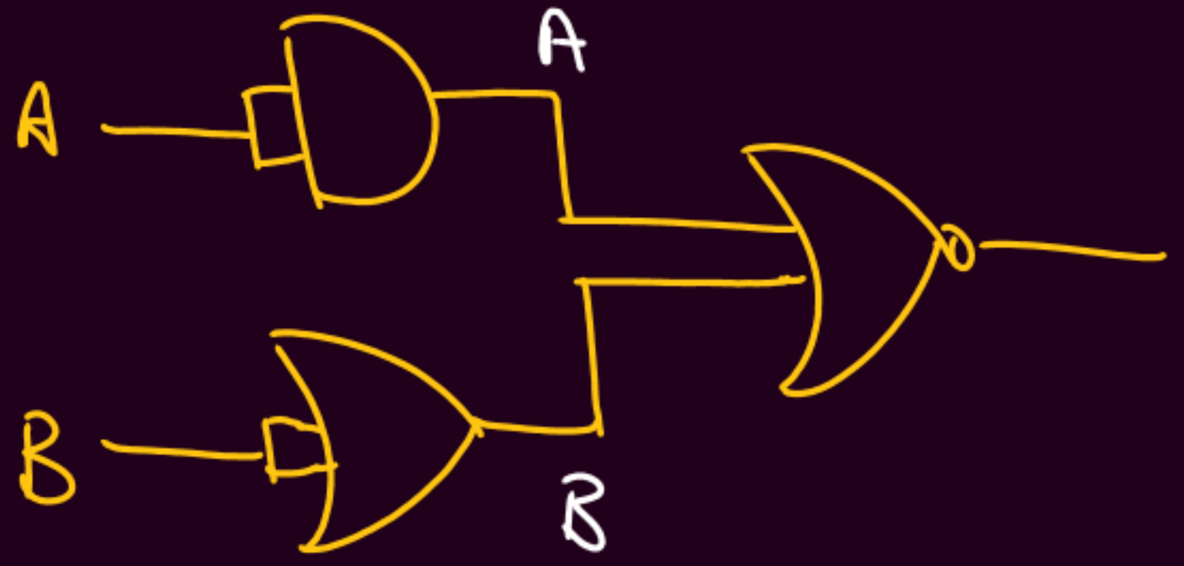




AND

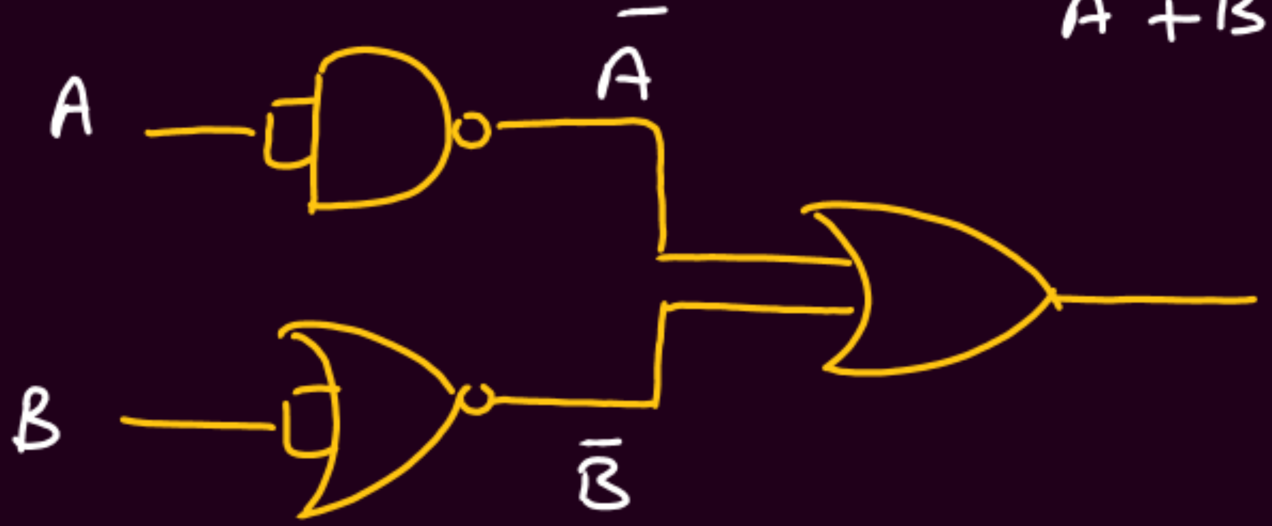


OR

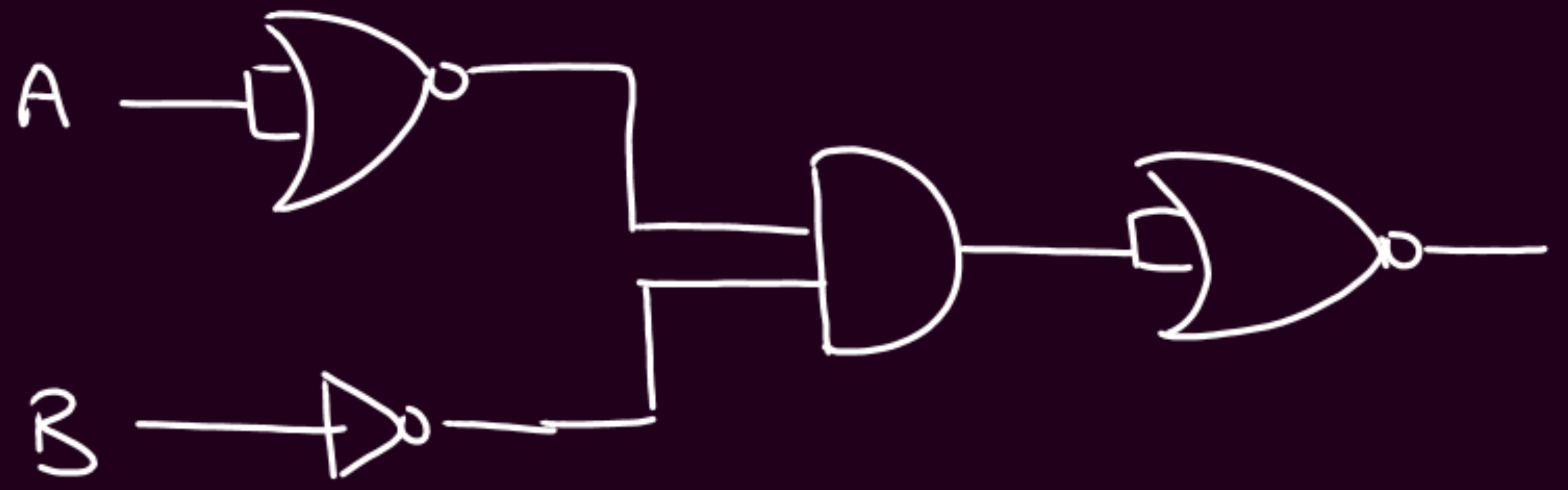


NOR

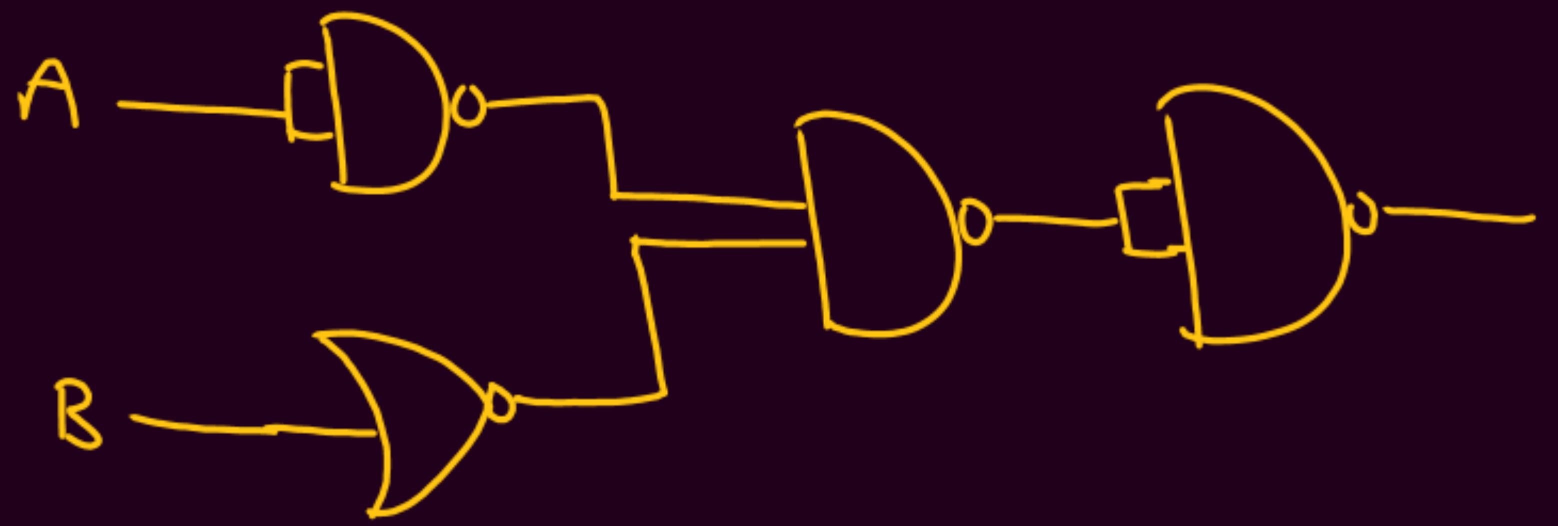
$\bar{A} + \bar{B} = \overline{A \cdot B}$



NAND



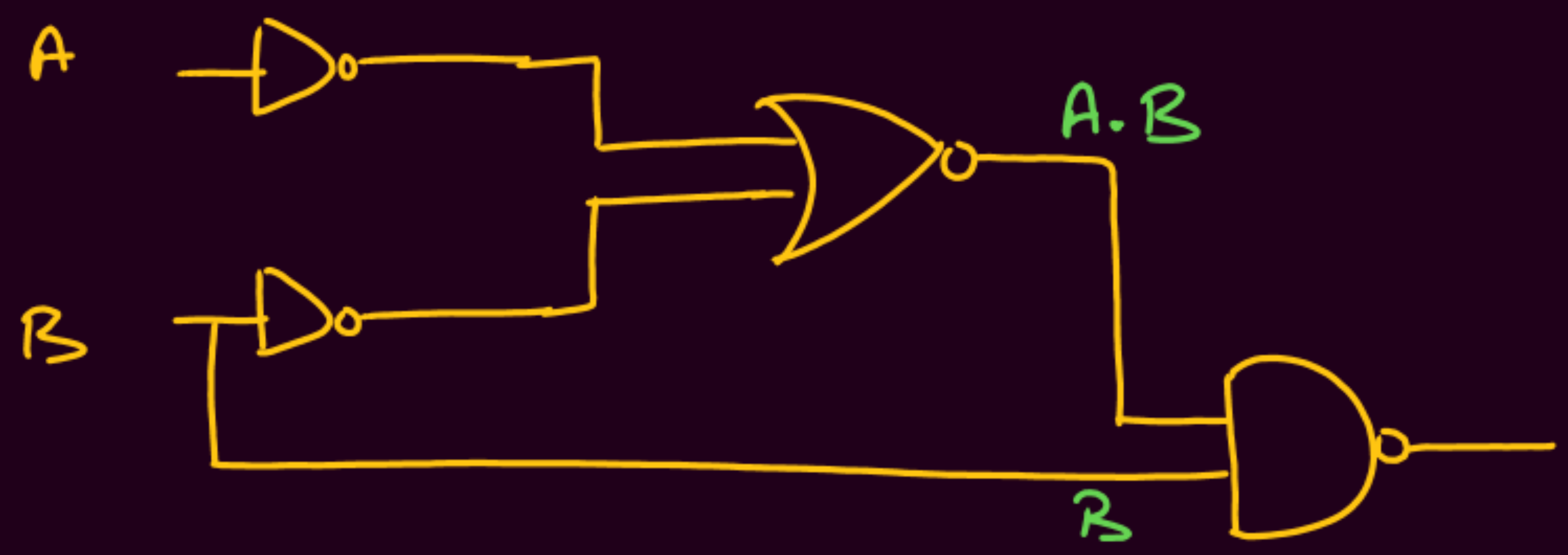
OR



NOR

A	B	C	Y
0	0	0	1
1	1	1	0
0	1	0	1
1	0	1	0

A. B	C	OR	NOR = Y
0	0	0	1
		1	0
1	1		
		0	1
0	0		
0	1	1	0



$$\overline{A.B.B} = \overline{A.B}$$

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

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

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

$$= \overline{A.B}$$

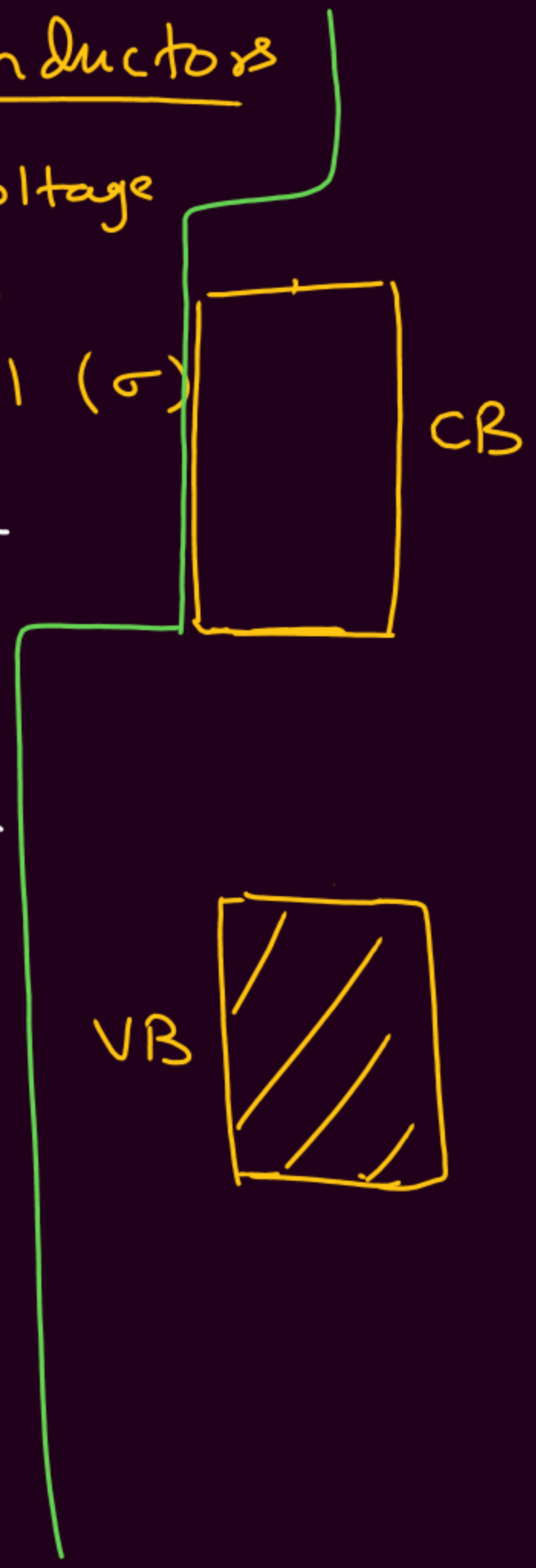
Semiconductors

- low voltage
- Cheap
- Control (σ)

Discrete

Continuous

Bands

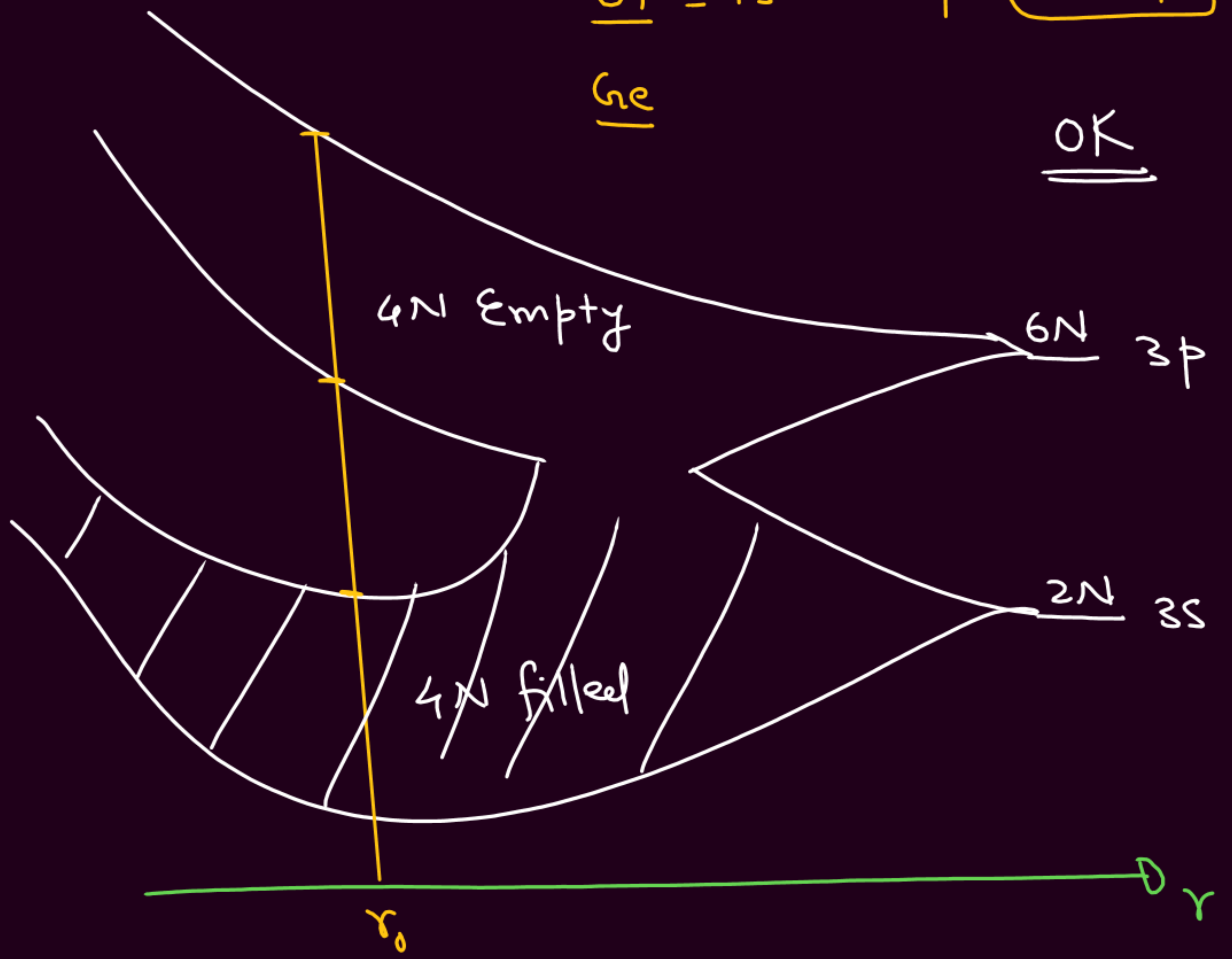


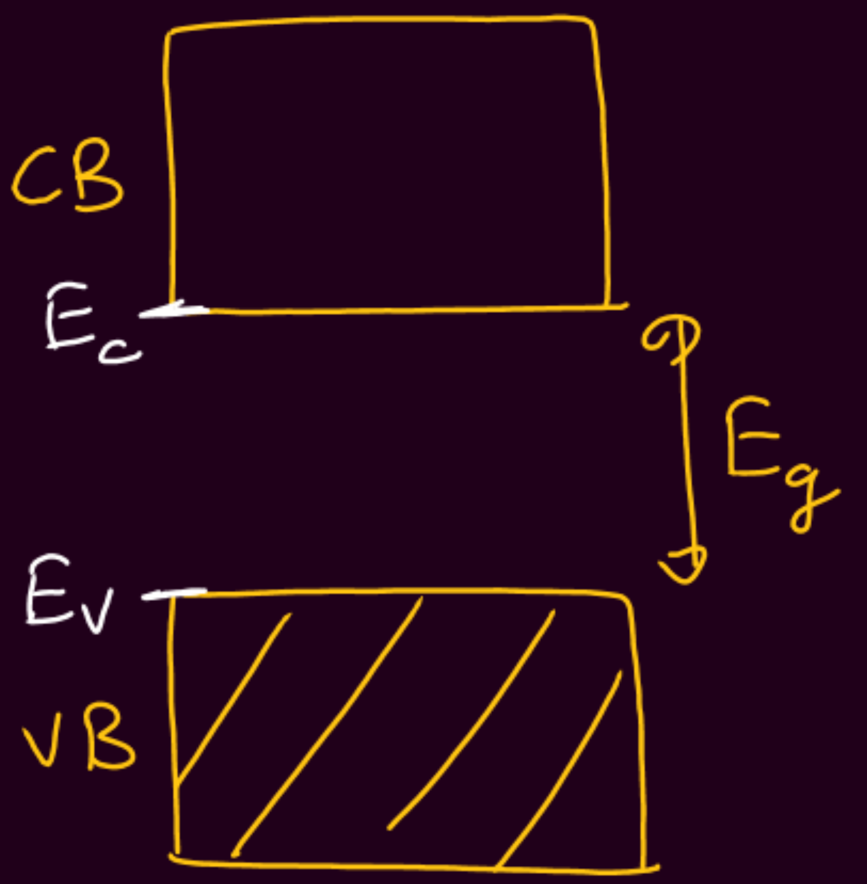
Band Theory

$Si = 1s^2 2s^2 2p^6 \boxed{3s^2 3p^2}$

Ge

OK





① VB → Highest fully occupied Energy Band

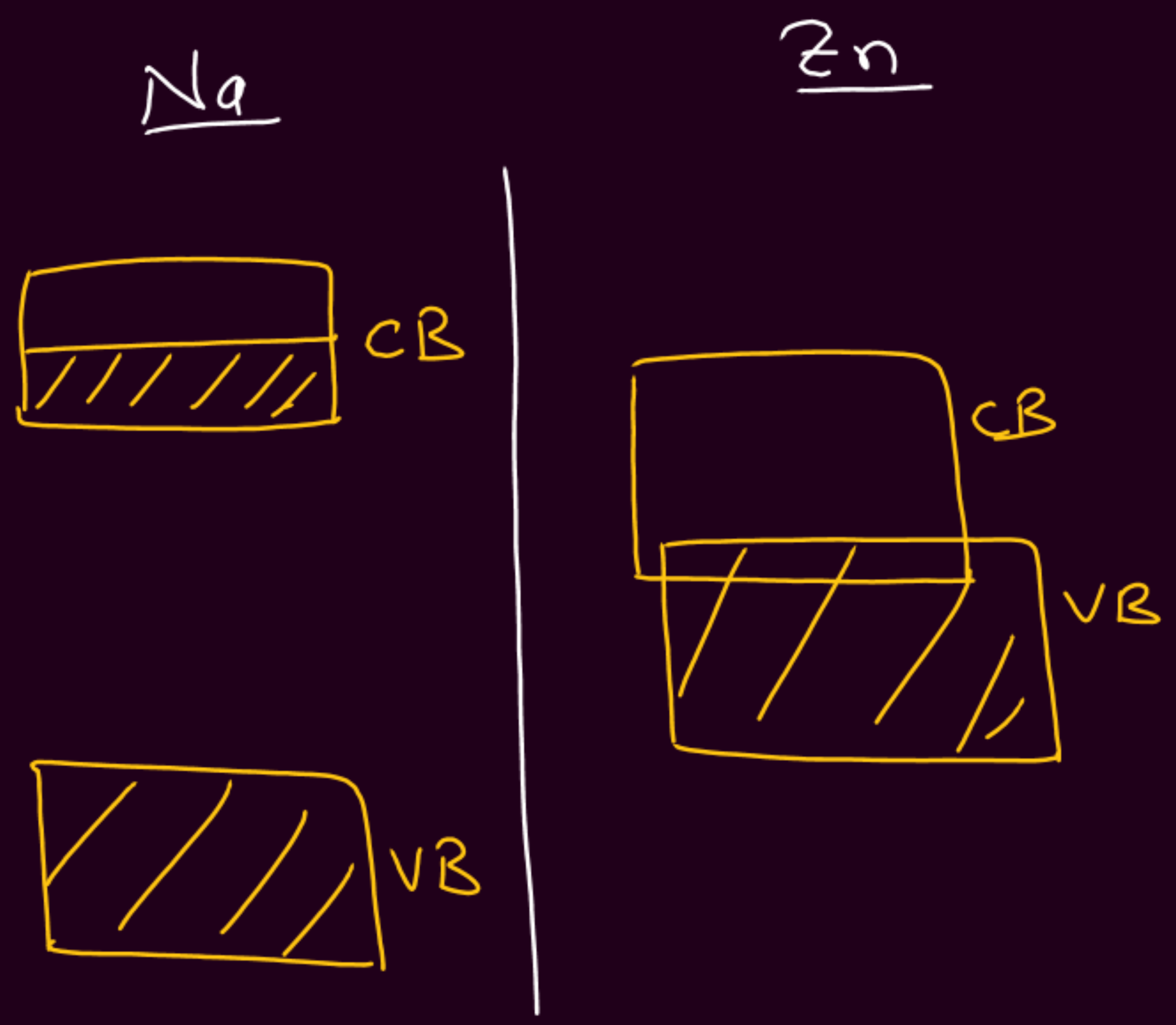
② CB → Lowest partially/completely Empty Energy Band

Band Gap (Forbidden) E_g

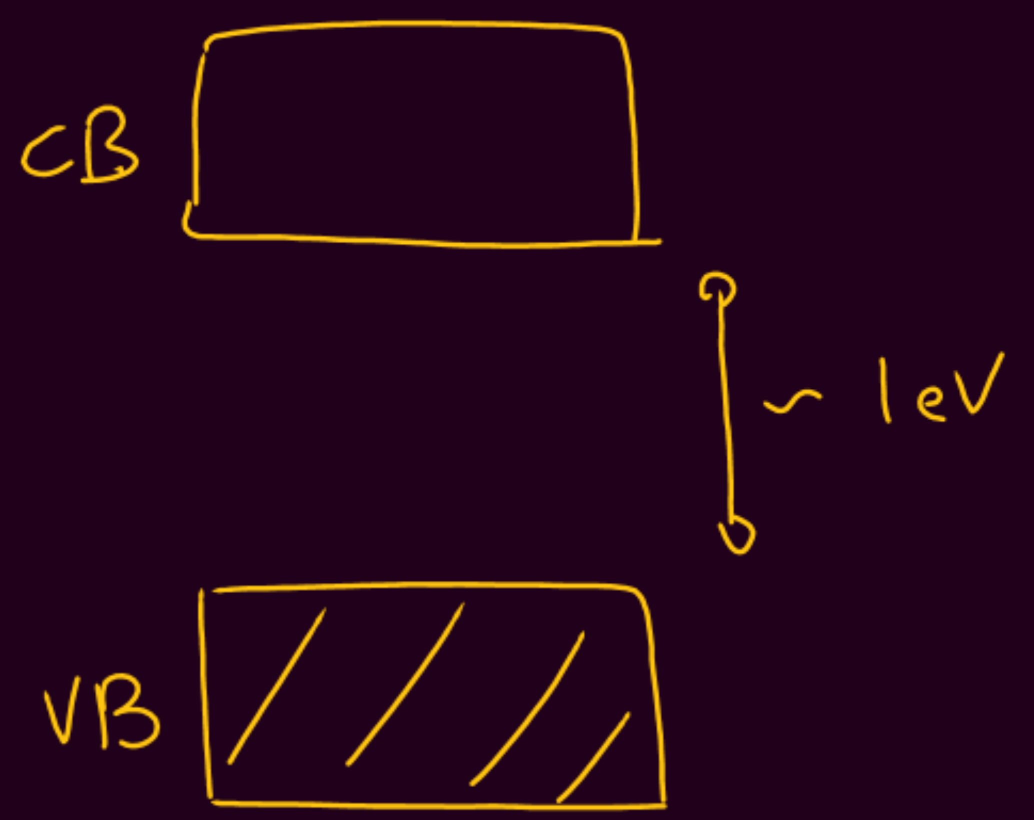
$$E_g = E_c - E_V$$

E_g = diff. of lowest energy level of CB and Highest —— " —————— VB

Conductors

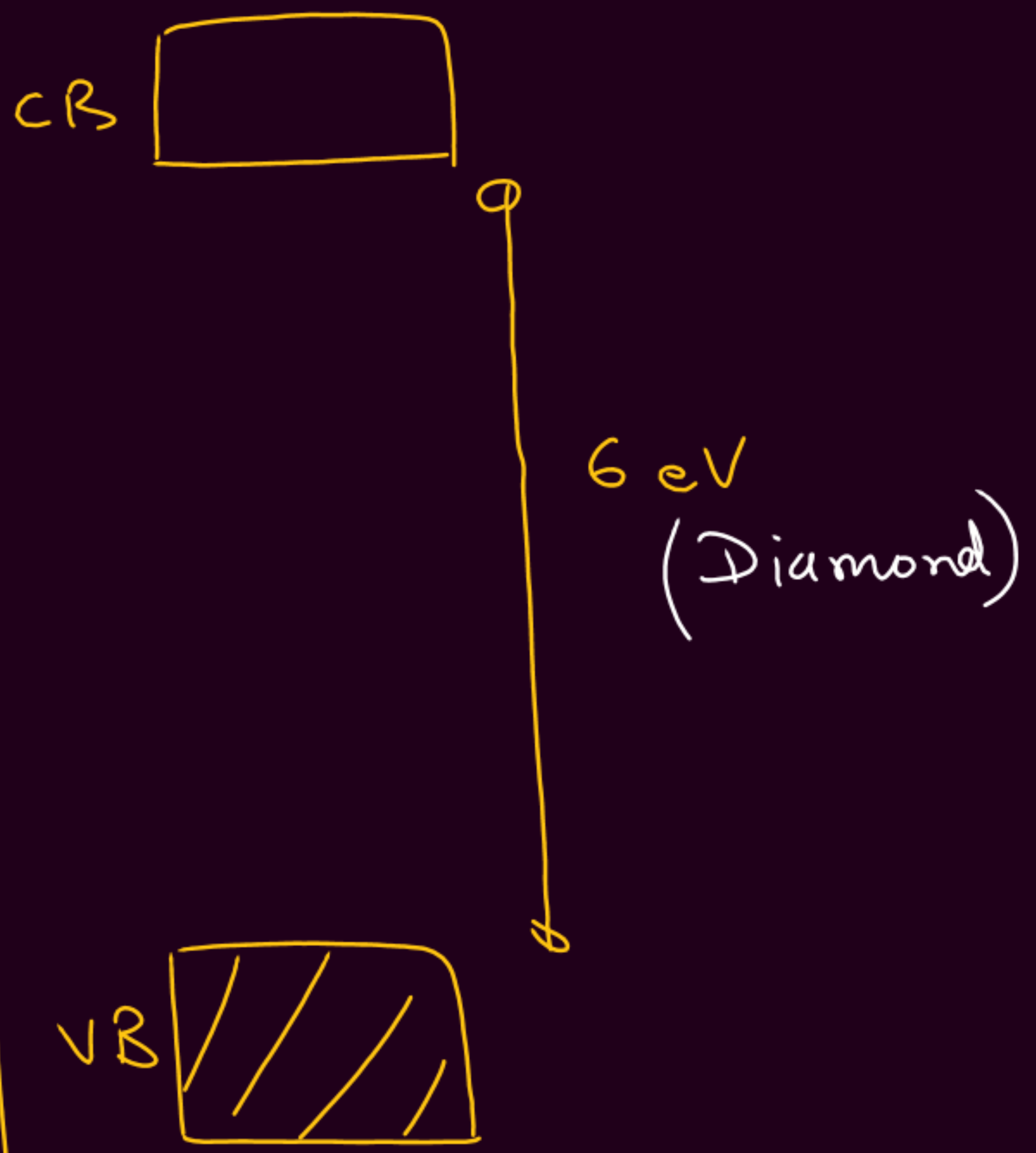


Semiconductors



Room Temp. $kT \simeq 0.026\,eV$

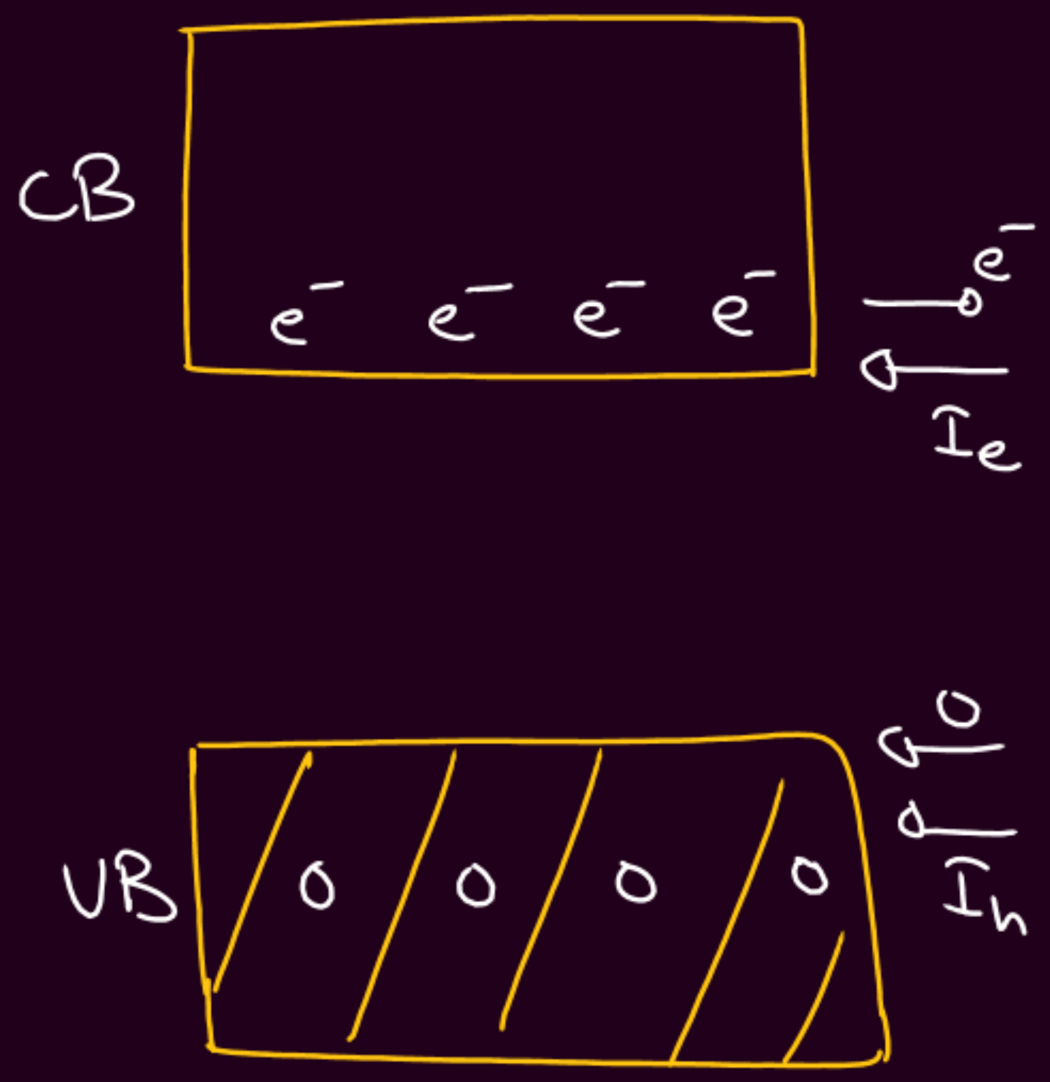
Insulators



Intrinsic SC

(Pure)

Room Temp.



$e^- \rightarrow$ electrons in CB

holes $\rightarrow$ vacant sites in VB

Rate of gen. of $e^- - h$ pair $\rightarrow$ Temp. ($T\uparrow \rightarrow$ Rate$\uparrow$)

n_i $\rightarrow$ Incident Radiation ($E_{ph} \geq E_g$)

$n_e = n_h = n_i$

$$\boxed{n_e n_h = n_i^2}$$

→ Recombination

→ Equilibrium

(Rate of gen.) = (Rate of Recomb.)

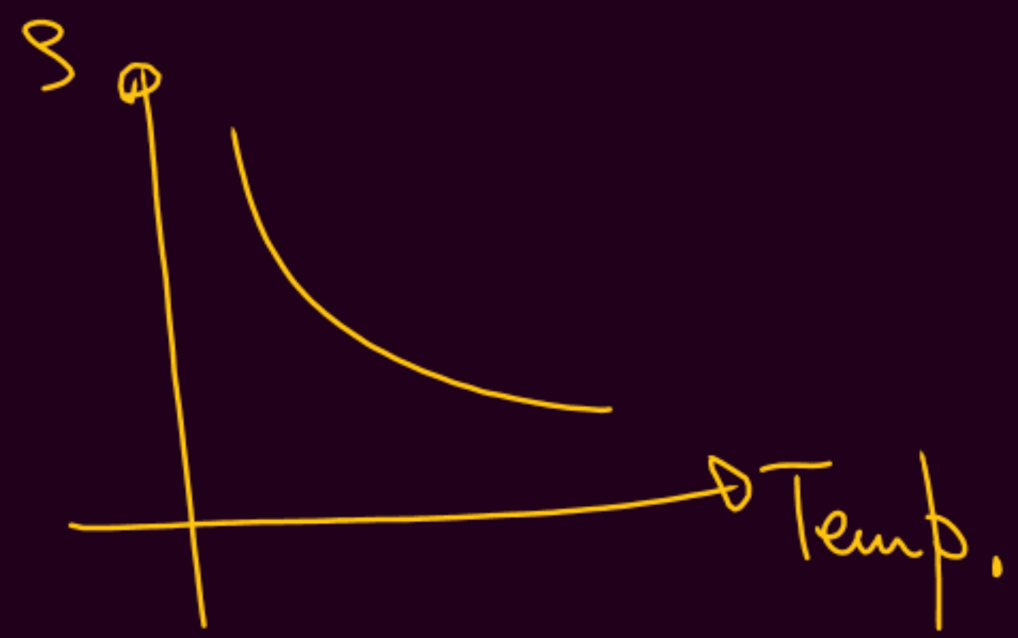
→ Mobility $\mu_e > \mu_h$

→ Effective mass of holes > e^-

→ Conductivity $\sigma = \sigma_e + \sigma_h = n_e e \mu_e + n_h e \mu_h$

→ Resistivity Temp $\uparrow$ $n \uparrow$ $\rho \downarrow$

$$\rho = \frac{m}{ne^2\tau}$$



Extrinsic SC

Doping → To Add Impurity

P-type

Al, Ga | Si, Ge

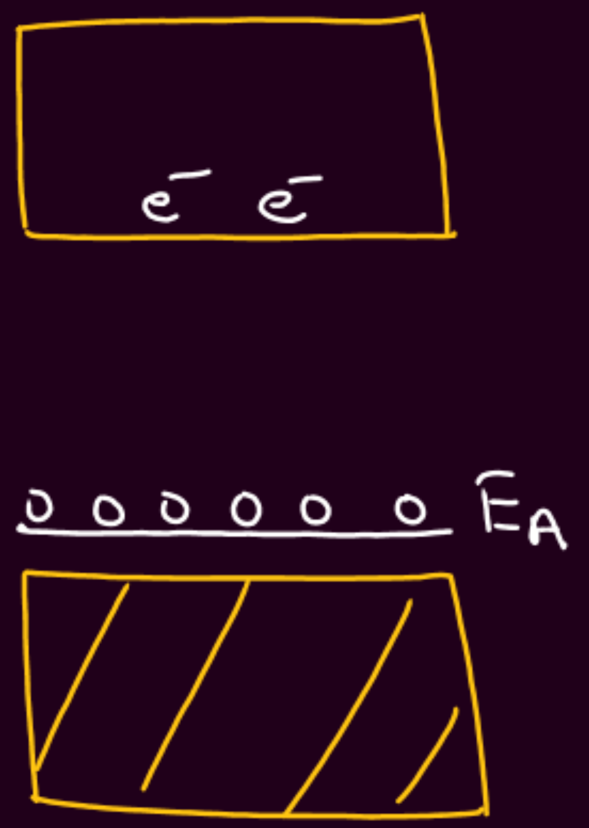
Trivalent / Acceptor

$n_e << n_h$

$I_e << I_h$

holes → majority

e^- → minority



$\boxed{\text{Neutral}}$

$n_i = 10^{15}\,/m^3$

$Si \Rightarrow 10^{28}\,/m^3$

$1\,ppm \sim 10^{22}\,/m^3$

$n_h \simeq 10^{22}\,/m^3$

$n_e n_h = n_i^2$

$n_e \simeq 10^{8}\,/m^3$

N-type

Si, Ge | P, As

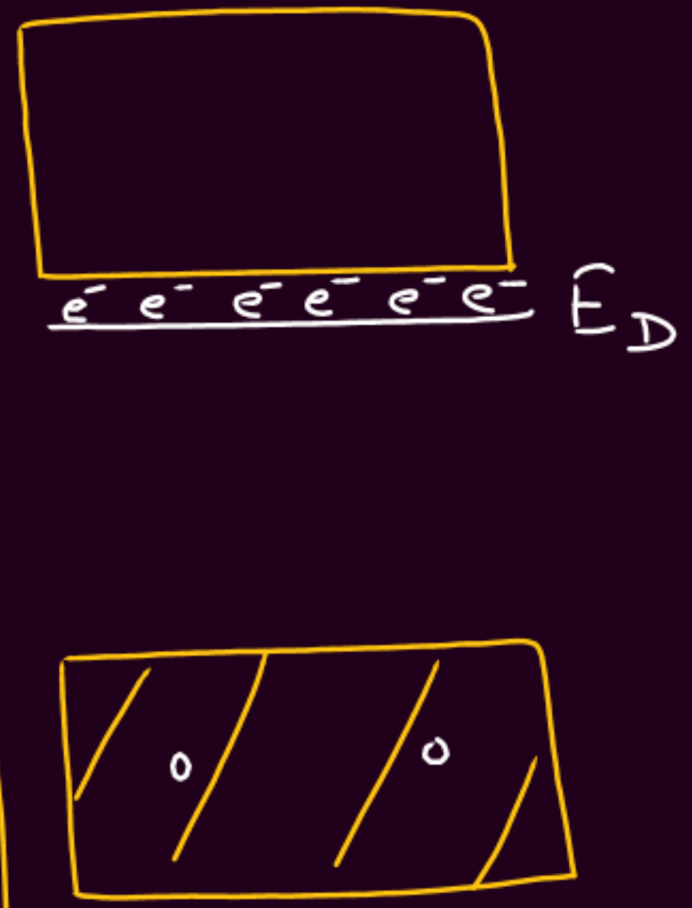
Pentavalent / Donor

$n_e >> n_h$

$I_e >> I_h$

e^- → majority

h → minority

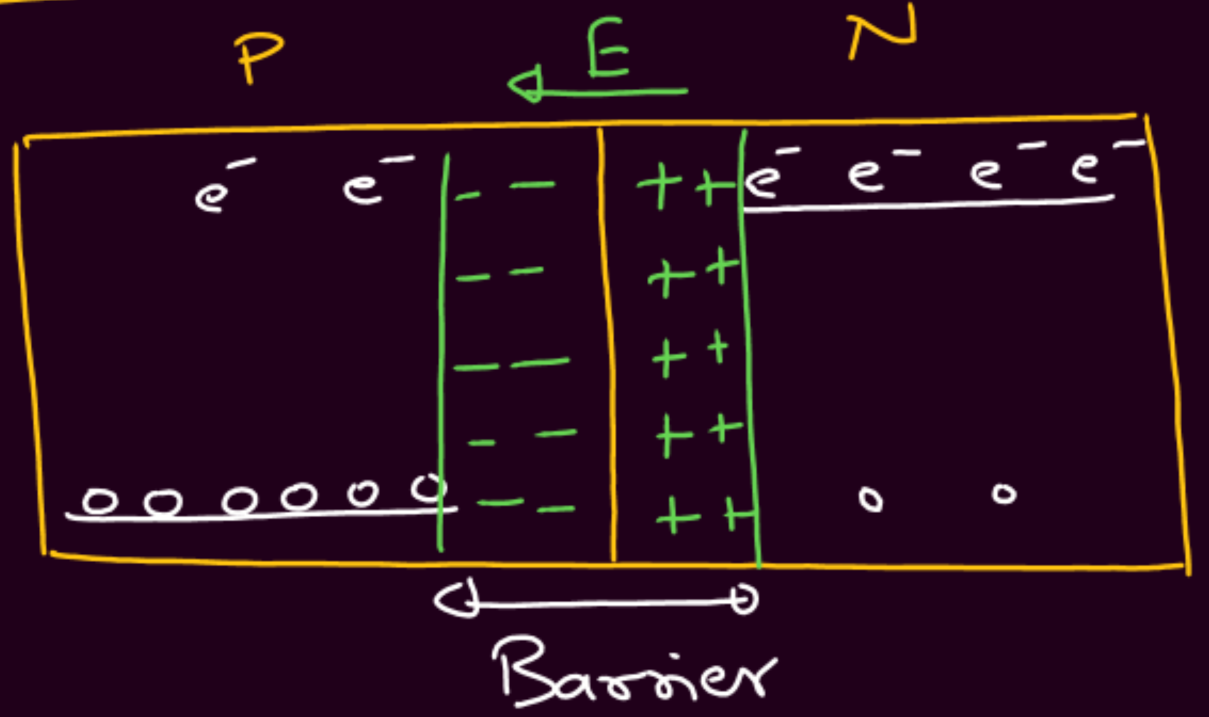


$\boxed{\text{Neutral}}$

$n_e \simeq 10^{22}\,/m^3$

$n_h \simeq 10^{8}\,/m^3$

P–N Junction Diode



Equilibrium

$I_{Diff} = I_{Drift}$

→ Diffusion
→ Conc. Gradient → Doping level
→ Diffusion current $\boxed{P \to N}$

} → majority charge Carriers

→ Depletion Region ~ (μm)
→ Depleted of charge carriers
→ Electric field [N → P]

$e^- \to N$

$h \to P$

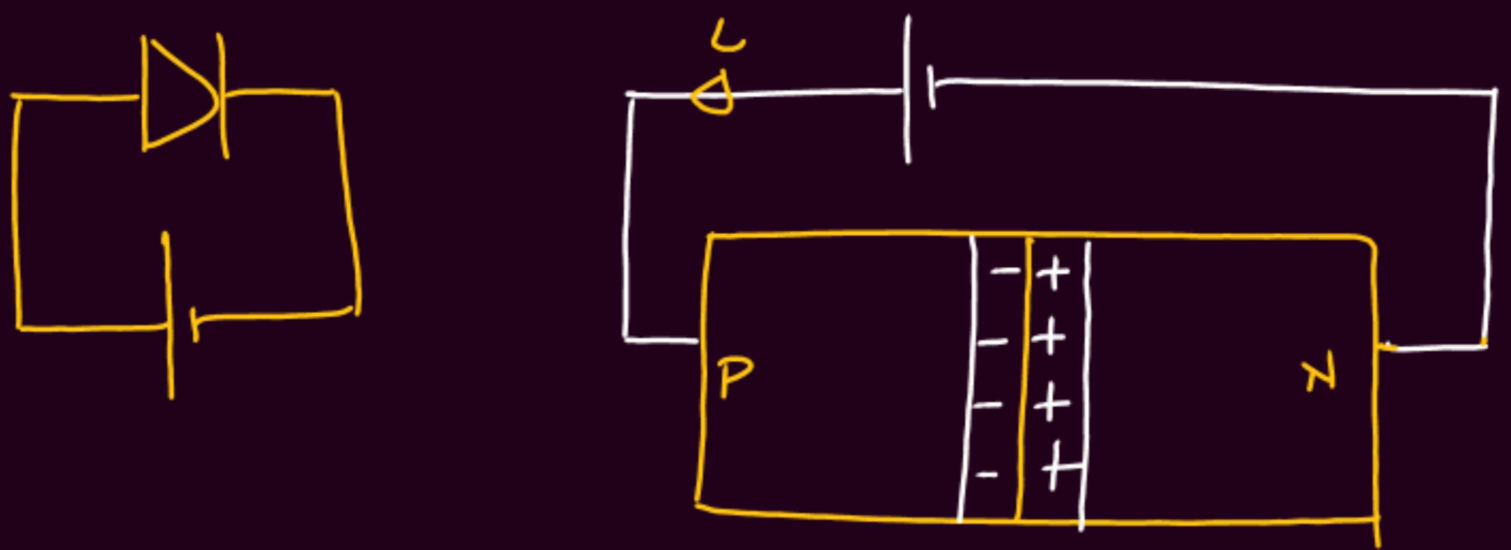
→ Minority charge carriers

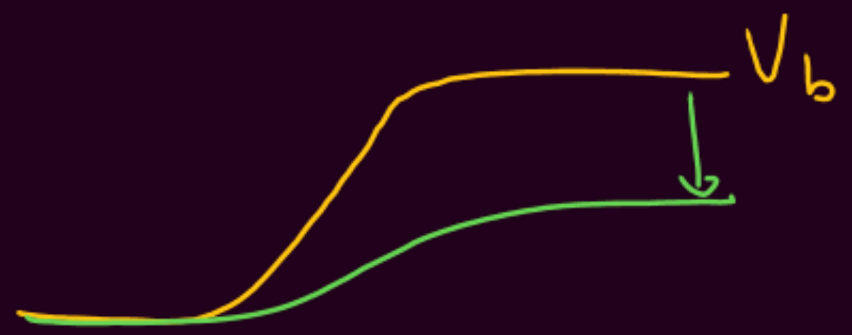
→ Drift current (N → P)

↳ Rate of gen of e^-h pair → Temp. / → Radiation

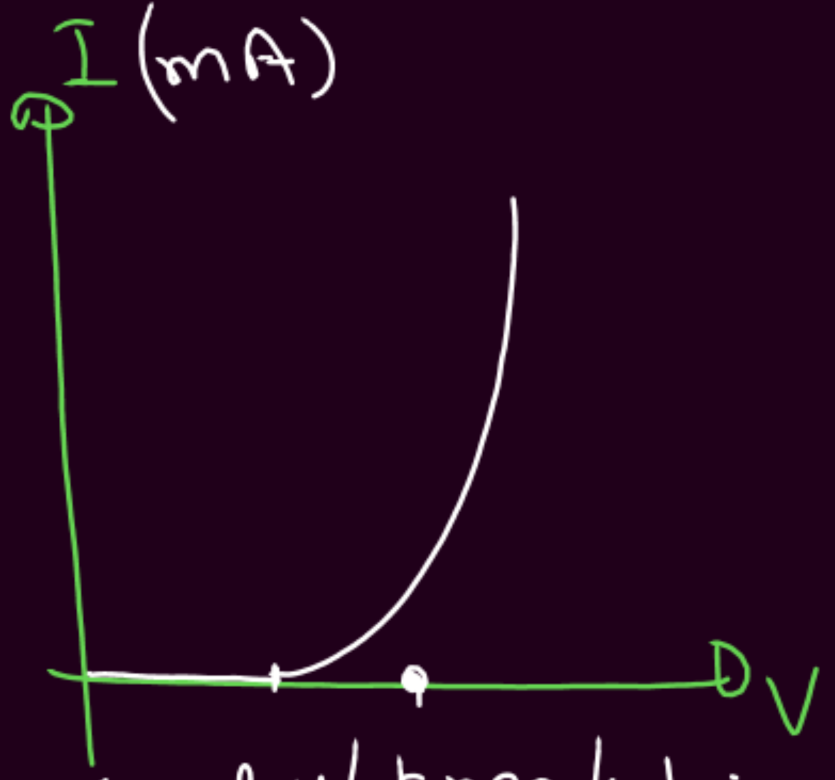
→ Barrier Potential → Si (0.7V) / → Ge (0.3V)

Forward Bias



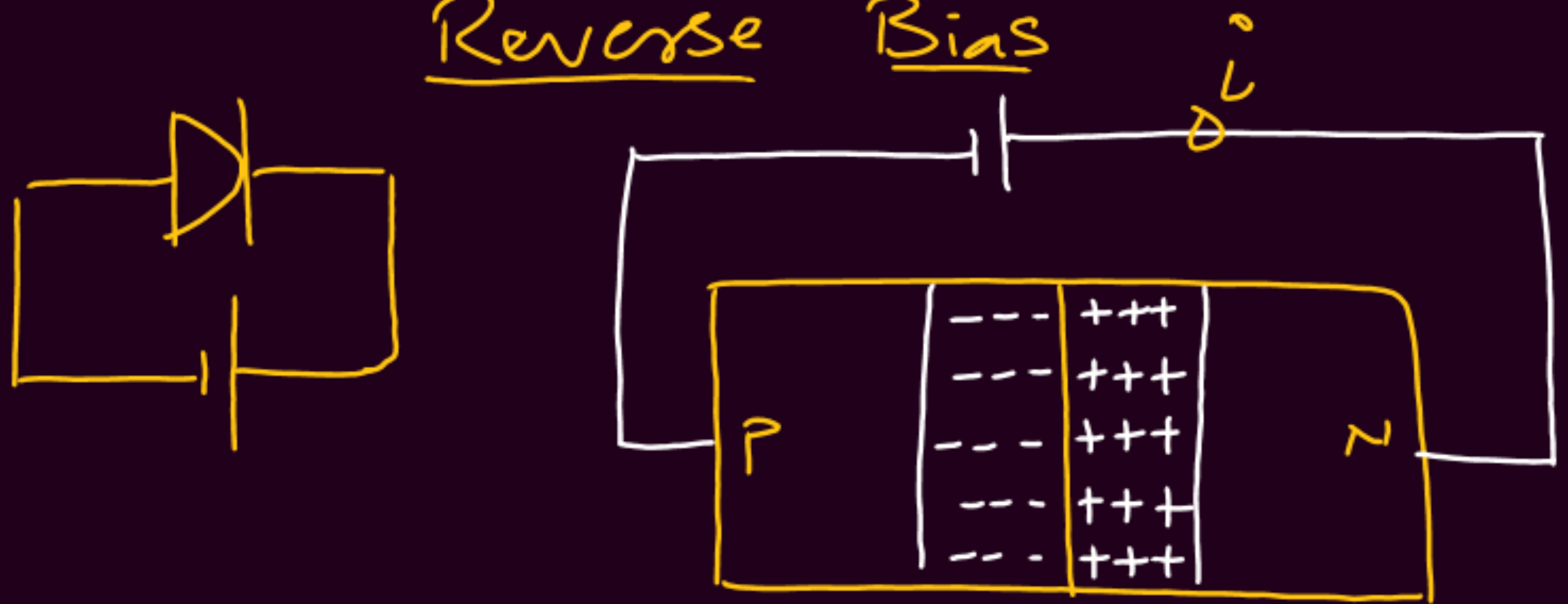


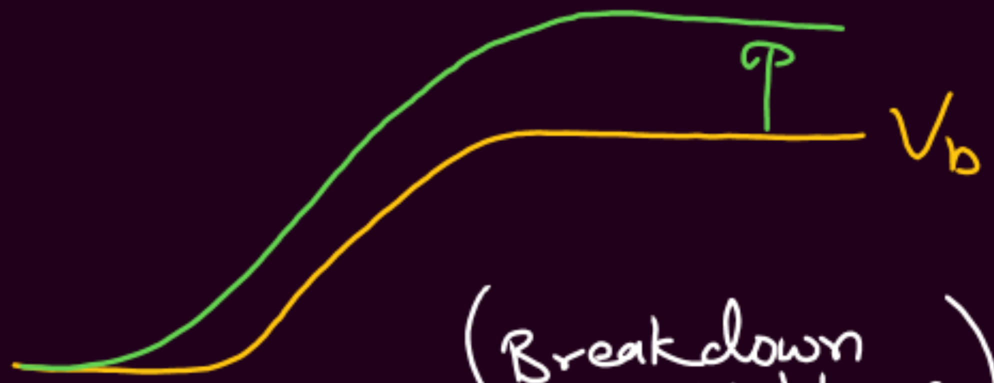
- → width D.R. ↓
- → $I_{diffusion}$ (mA)
- → (majority) $\boxed{P \to N}$
- → Barrier Potential ↓



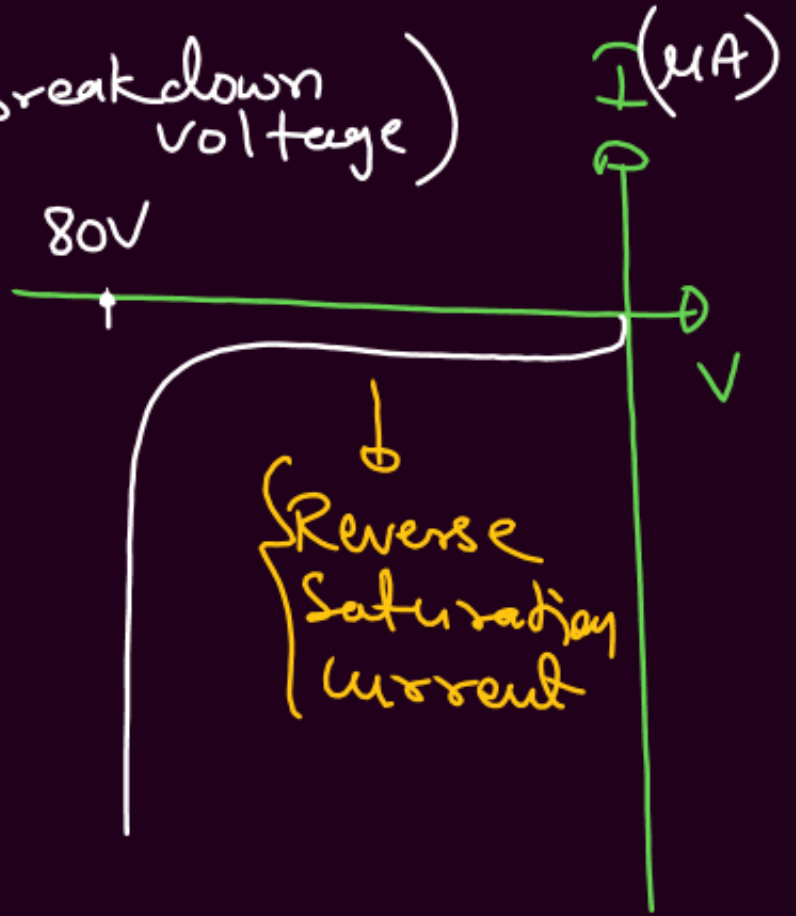
Threshold/ knee/cut-in
Si 0.7V
Ge 0.3V

Reverse Bias

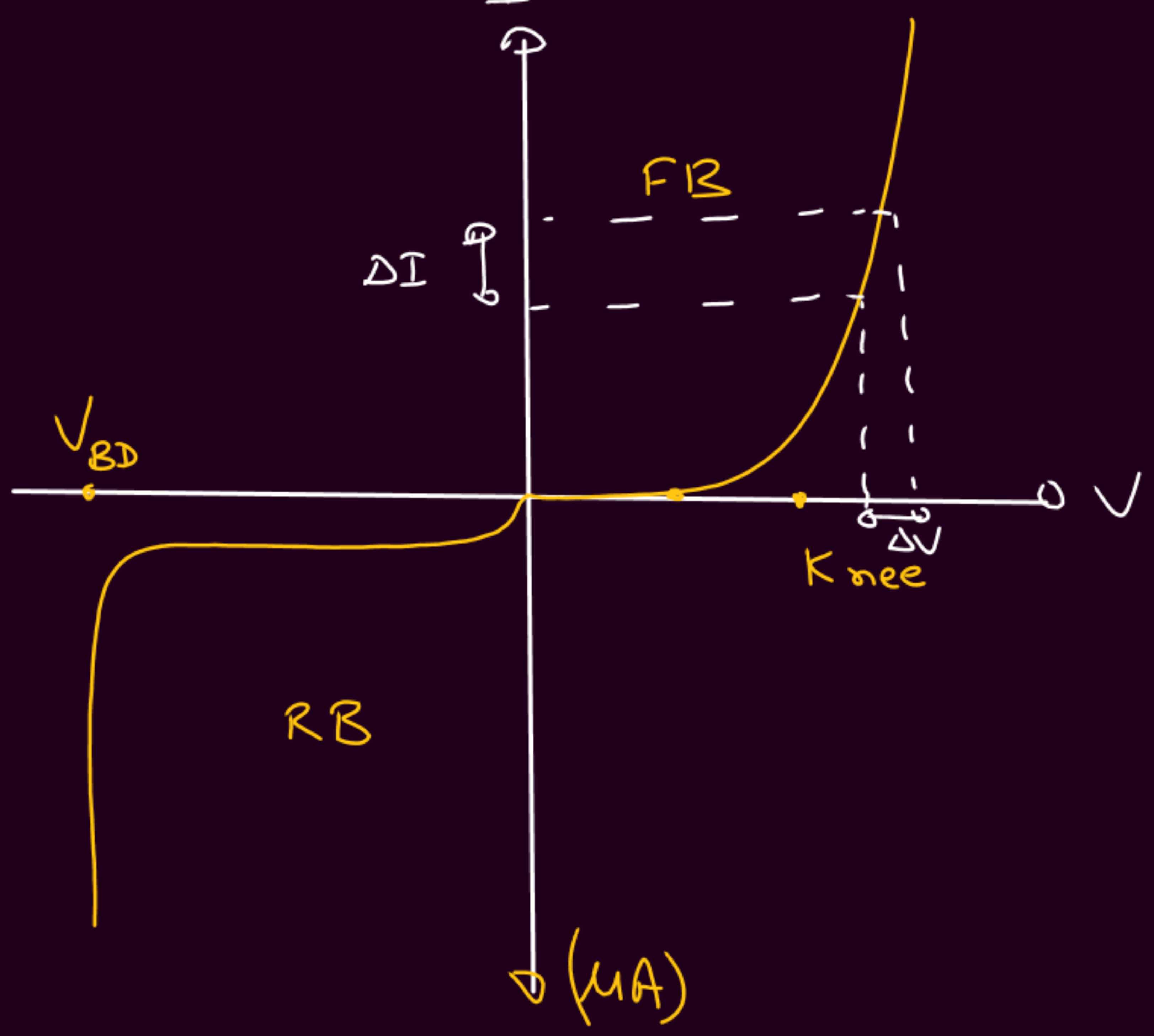




- → width D.R. ↑
- → Barrier Potential ↑
- → Drift current (μA)
- → minority (Temp. Radiation) $\boxed{N \to P}$



I - V characteristic



Dynamic Resistance

$$r_d = \frac{\Delta V}{\Delta I} \propto \frac{1}{(\text{Slope of I vs V})}$$

$r_{FB} \sim k\Omega$

$r_{RB} \sim M\Omega$

FB → SC

RB → OC

Q.

FB

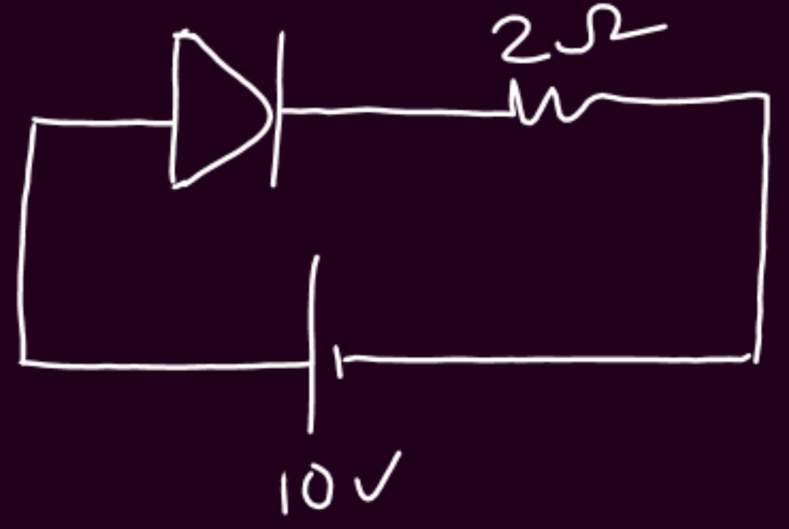
RB

RB

RB

FB

Q.

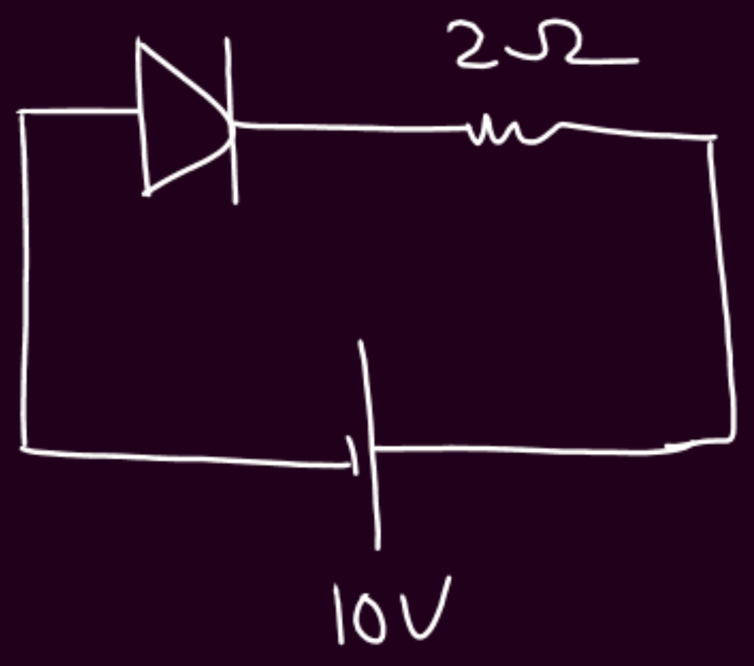


$i = \frac{10}{2} = 5A$

$V_D = 0$

$V_R = 10V$

Q.

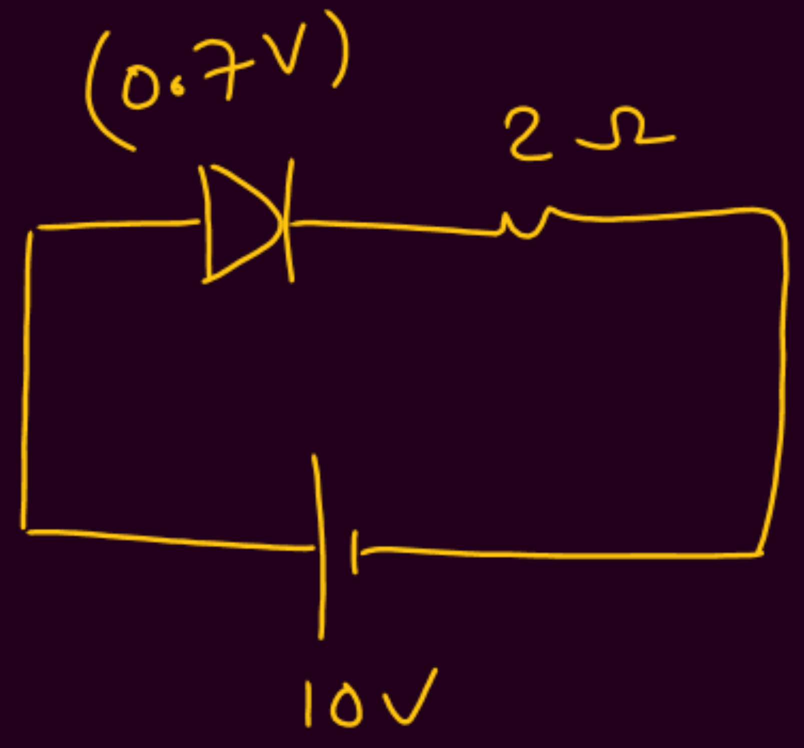


$i = 0$

$V_D = 10V$

$V_R = 0$

Q.



$$i = \frac{10 - 0.7}{2} = 4.65\,A$$

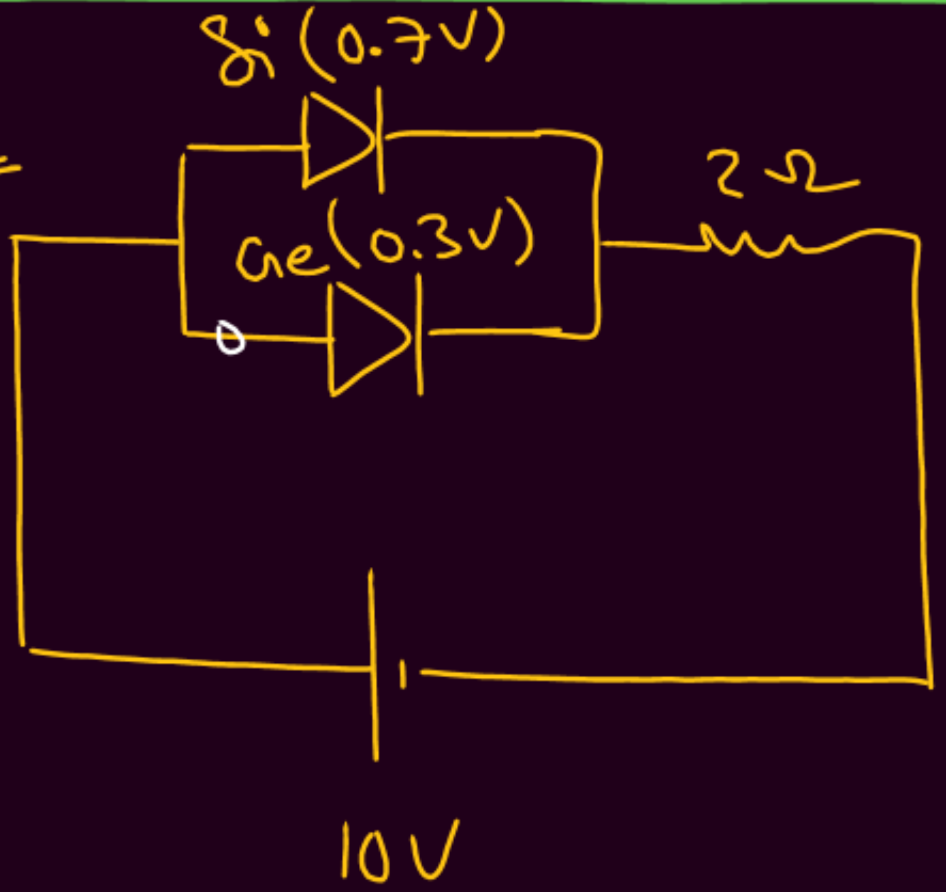
$$V_D = 0.7\,V$$

$$V_R = 9.3\,V$$

Q.

Current in Each Branch?

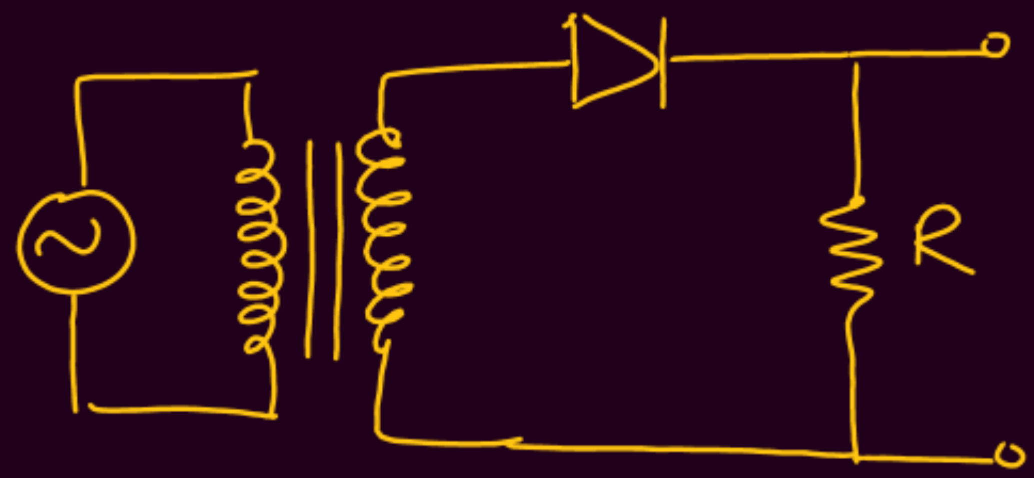
Q.

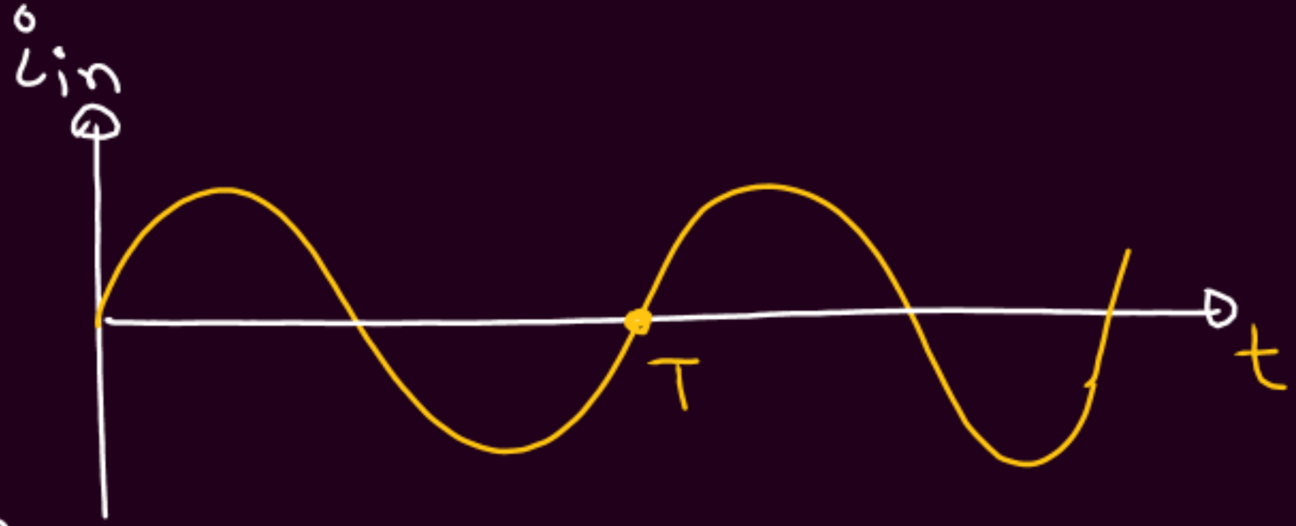


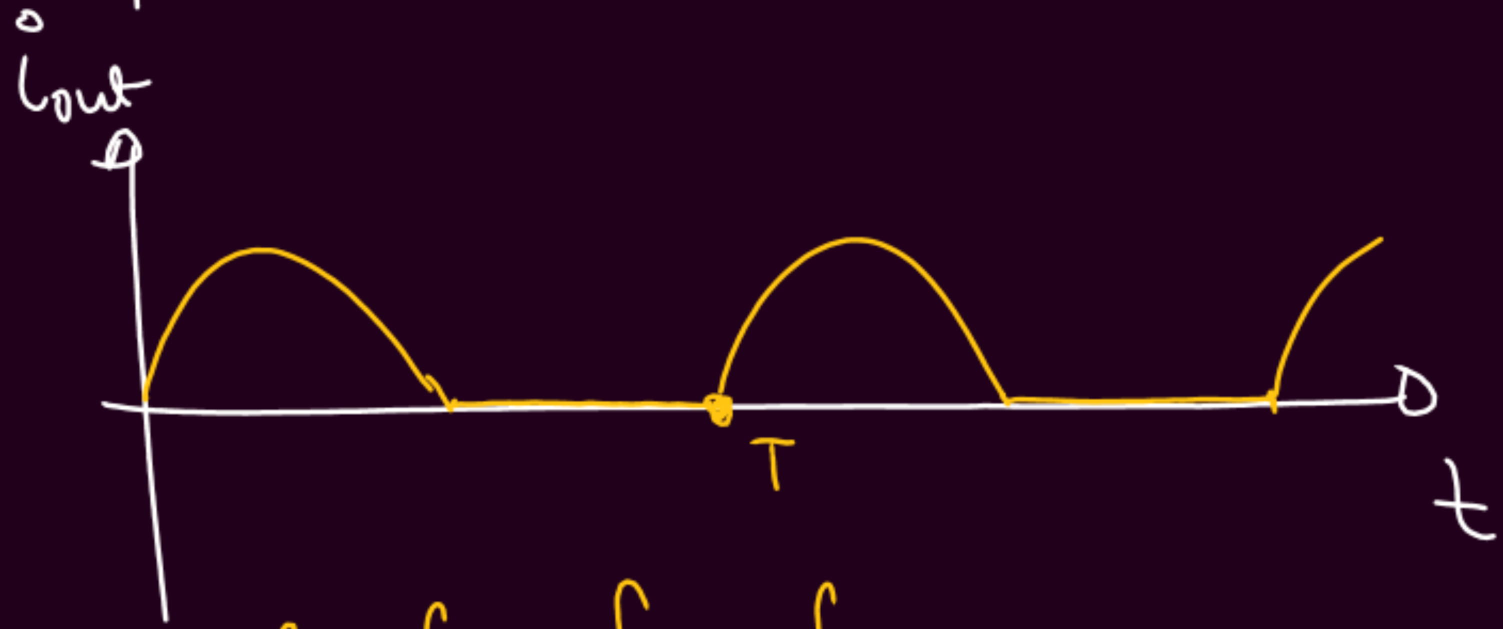
$$i = \frac{10 - 0.3}{2} = 4.85\,A$$

Apps

① Half Wave Rectifier



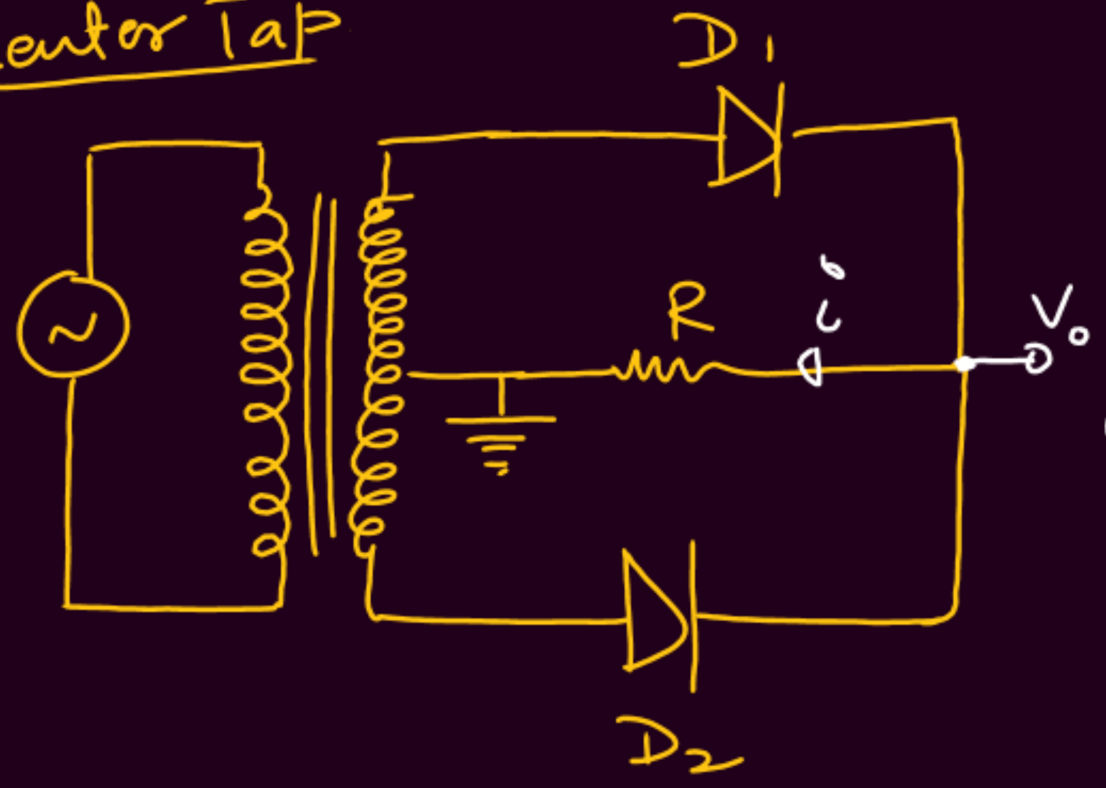


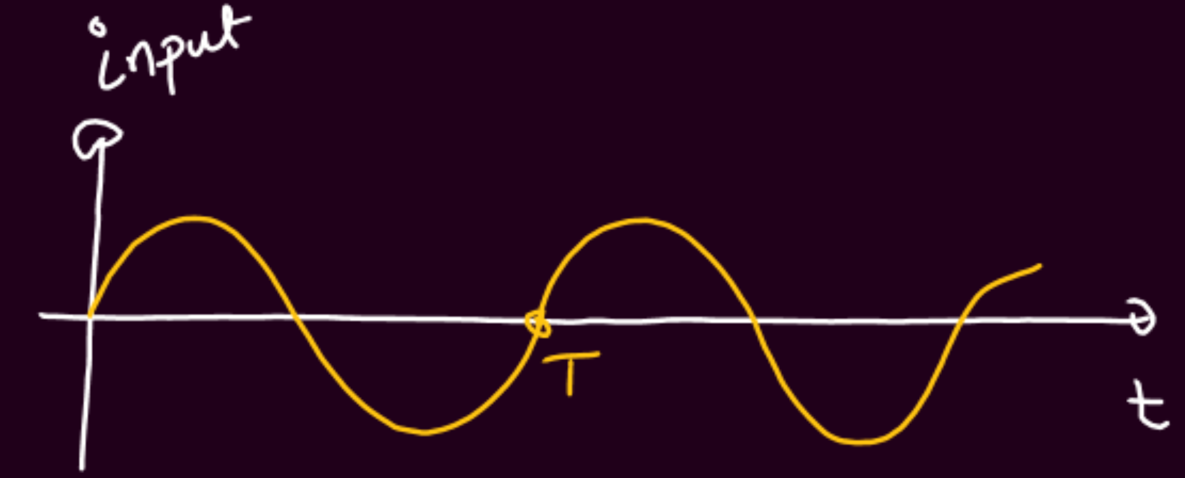


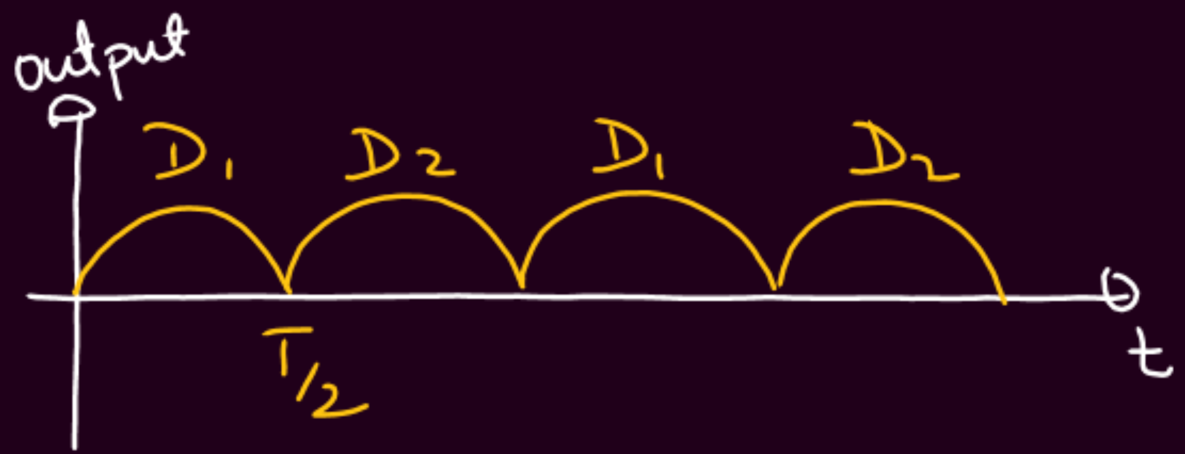
$f_{in} = f_0$ $\quad f_{out} = f_0$

② Full Wave Rectifier

Center Tap



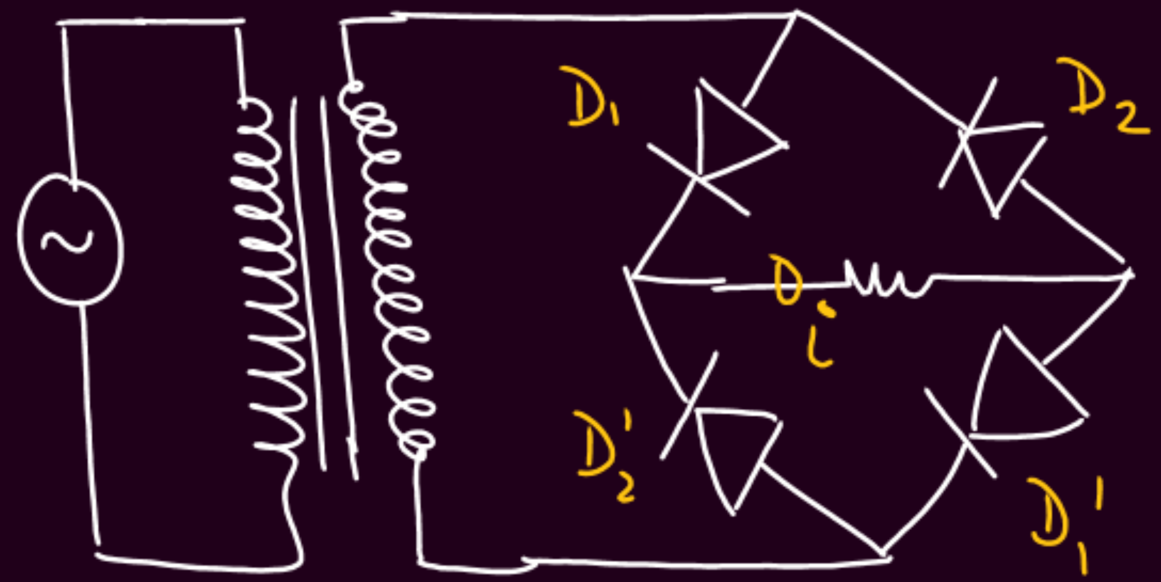




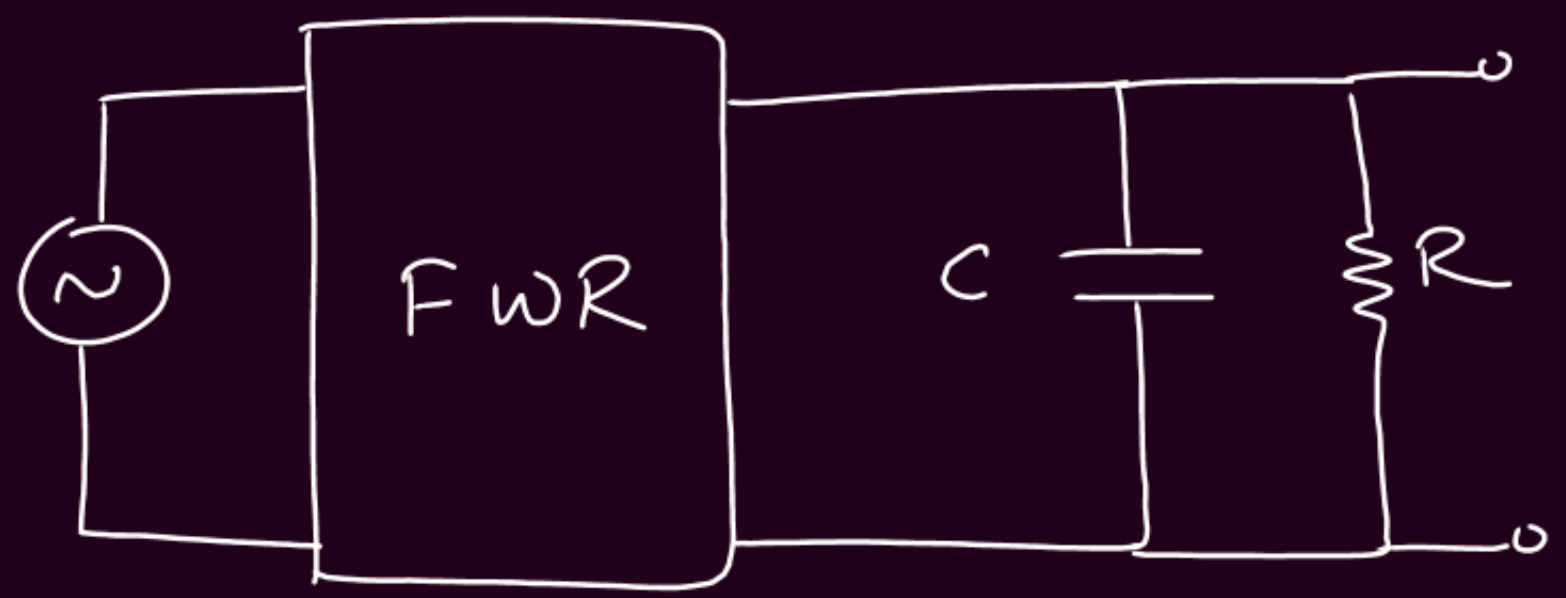
input → f $\quad T$

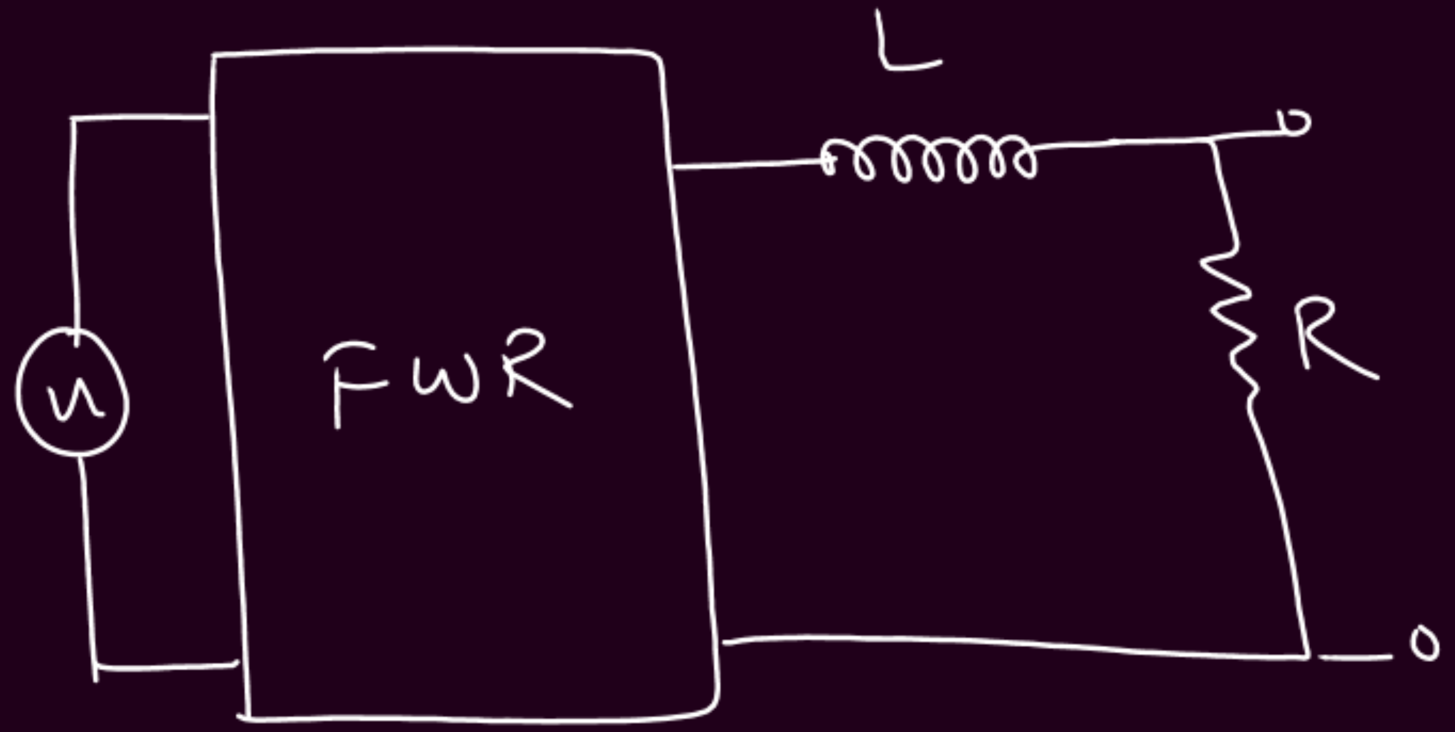
output → $2f$ $\quad T/2$

Bridge

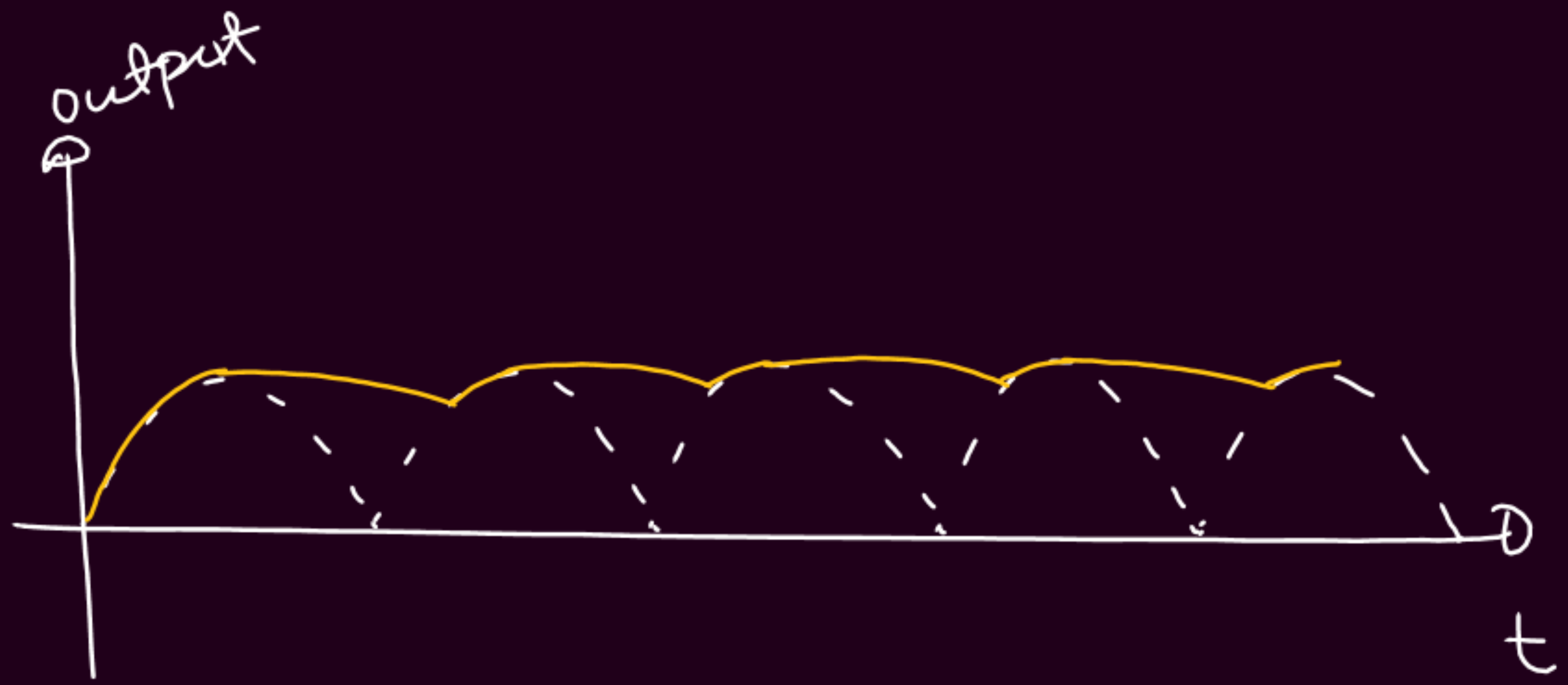


Filters → To remove ripples

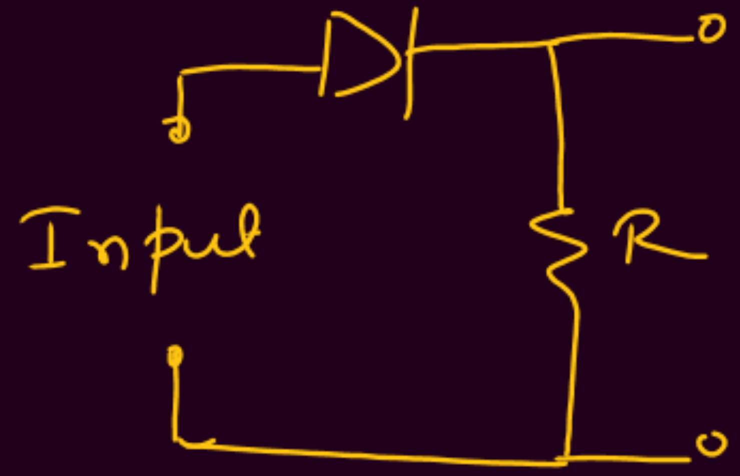




C in parallel
L in series
of large value



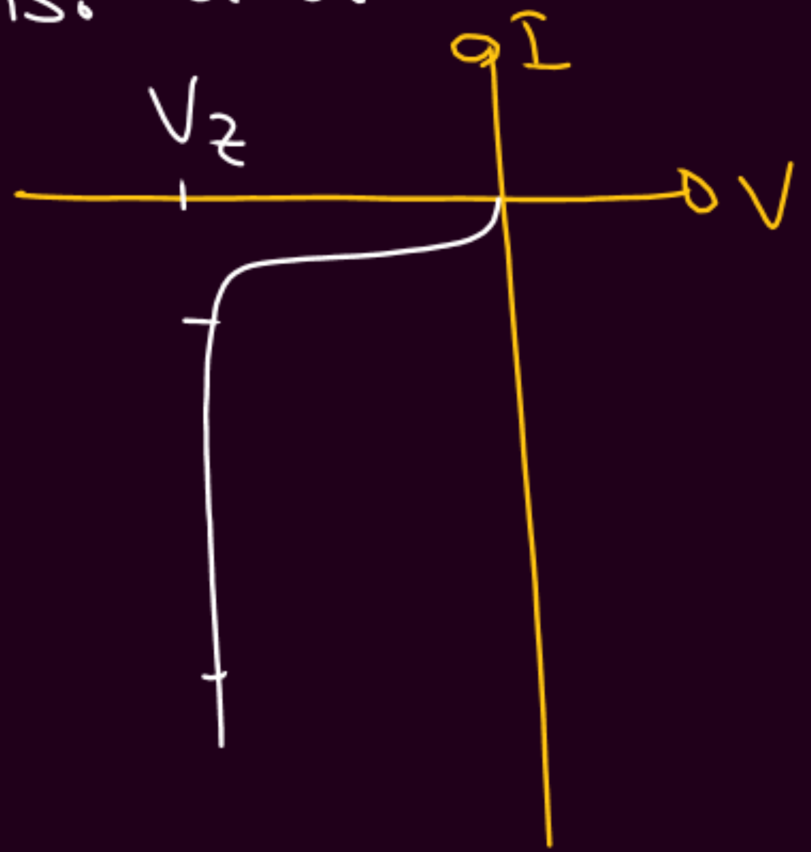
	HWR	FWR
Ripple factor	1.21	0.48
Efficiency	40.6%	81.2%

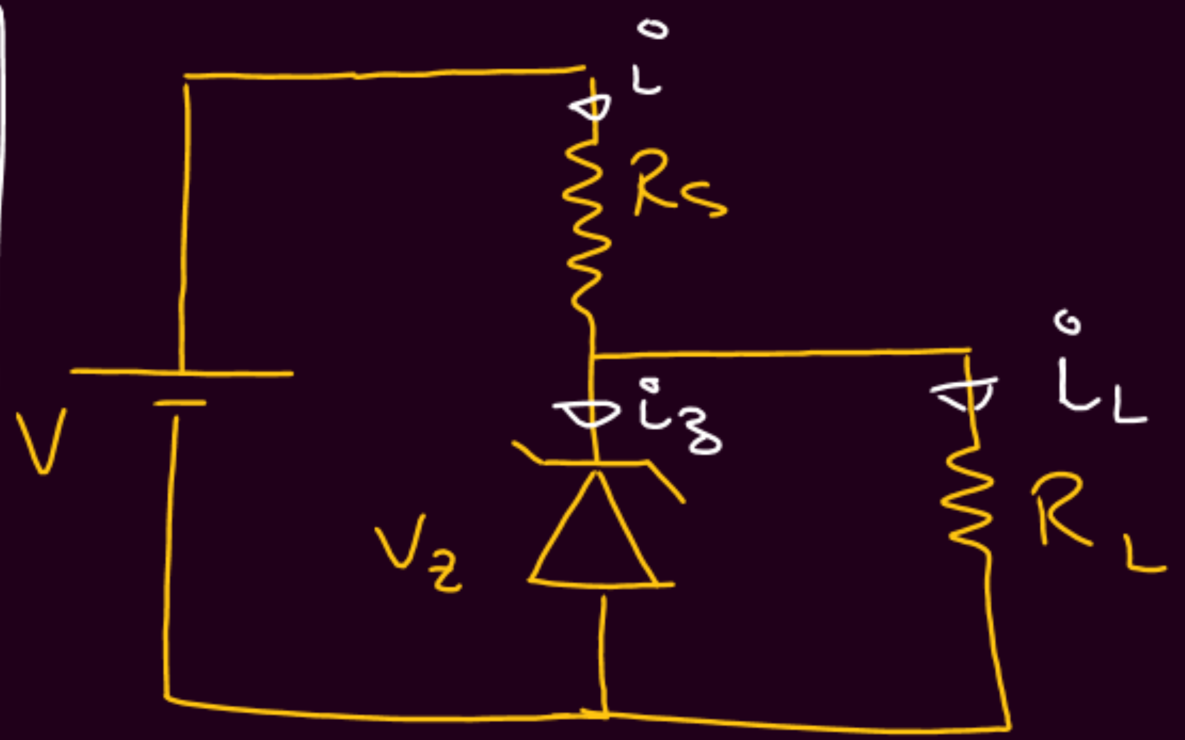


$\boxed{\text{HWR}}$

Zener Diode

- Voltage Regulator
- Both P & N
  - Heavily Doped
- Width of D.R. very small
- B.D. voltage (Rating V_z)
  - (5V)
- Used in R.B. under B.D.





KVL

1. $V_z = i_L R_L$

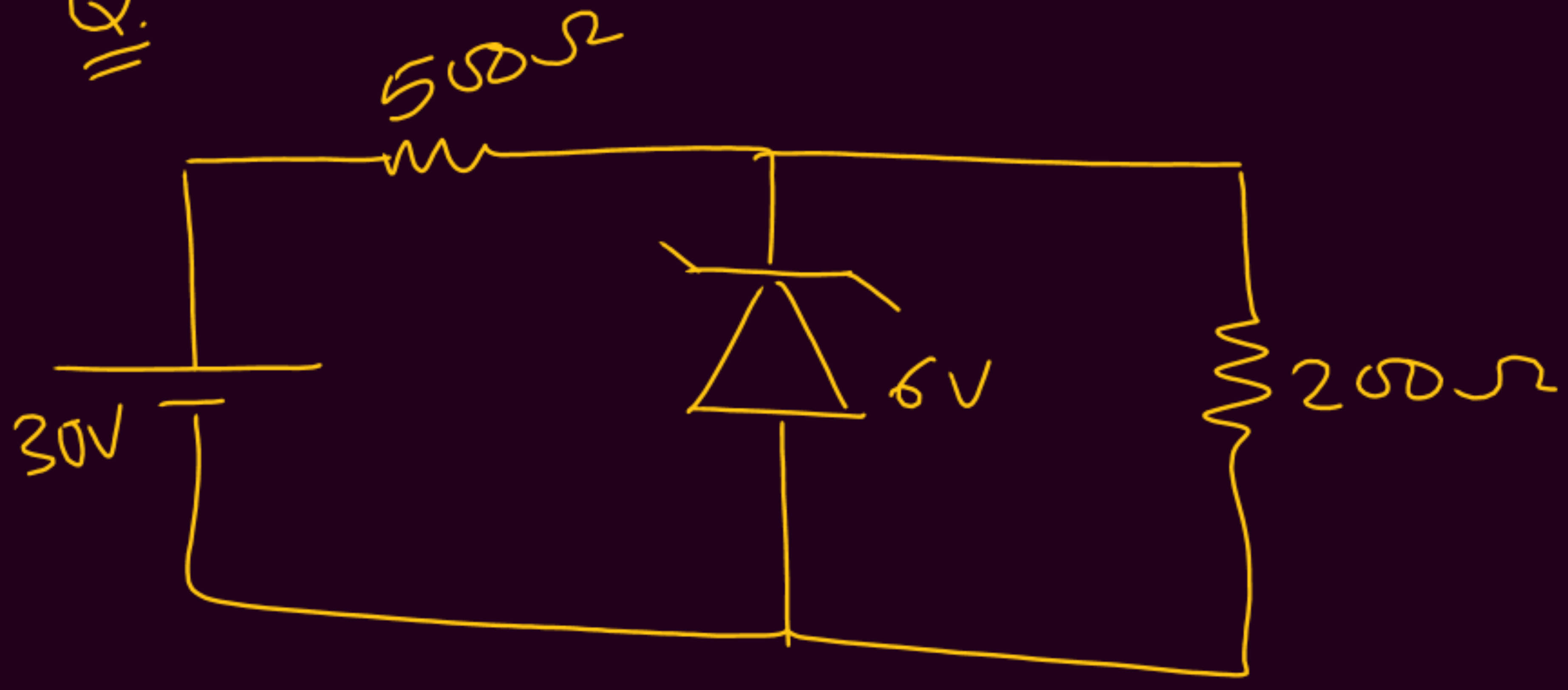
KVL

2. $V - V_z = i R_s$

KCL

3. $i_z = i - i_L$

Q.



$i_z = ?$

① $6 = i_L \, 200$

$i_L = 0.03\,A$

② $30 - 6 = i(500)$

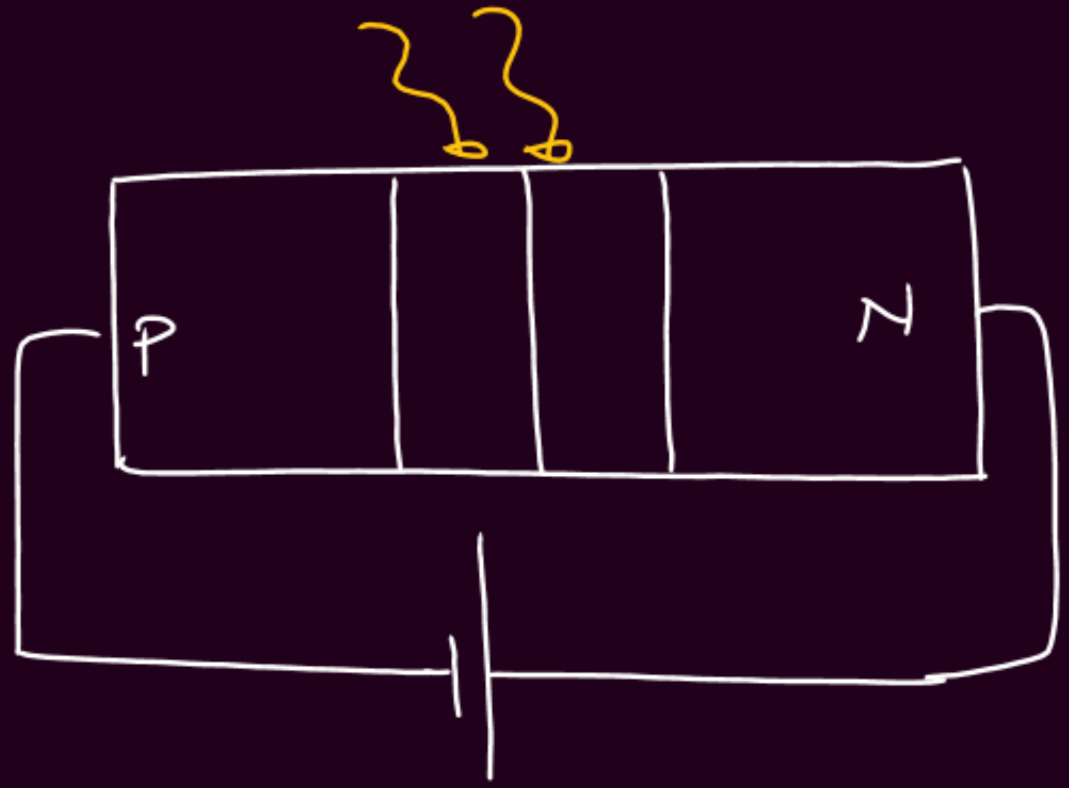
$i = 0.048\,A$

③ $i_z = 0.018\,A = \underline{18\,mA}$

Avalanche B.D.	Zener B.D.
→ Low Doping (Low $\vec{E}$)	→ Heavy Doping (Large $\vec{E}$)
→ Collision of e^-	→ Quantum Tunneling
→ Low B.D. voltage	→ High B.D. voltage
→ Excessive Heat	→ Reversible
→ Damage	
→ Temp. ↑ B.D. voltage ↑	→ Temp. ↑ B.D. voltage ↓

Optoelectronic Devices

① Photodiode



→ Radiation ($E_{ph} > E_g$)

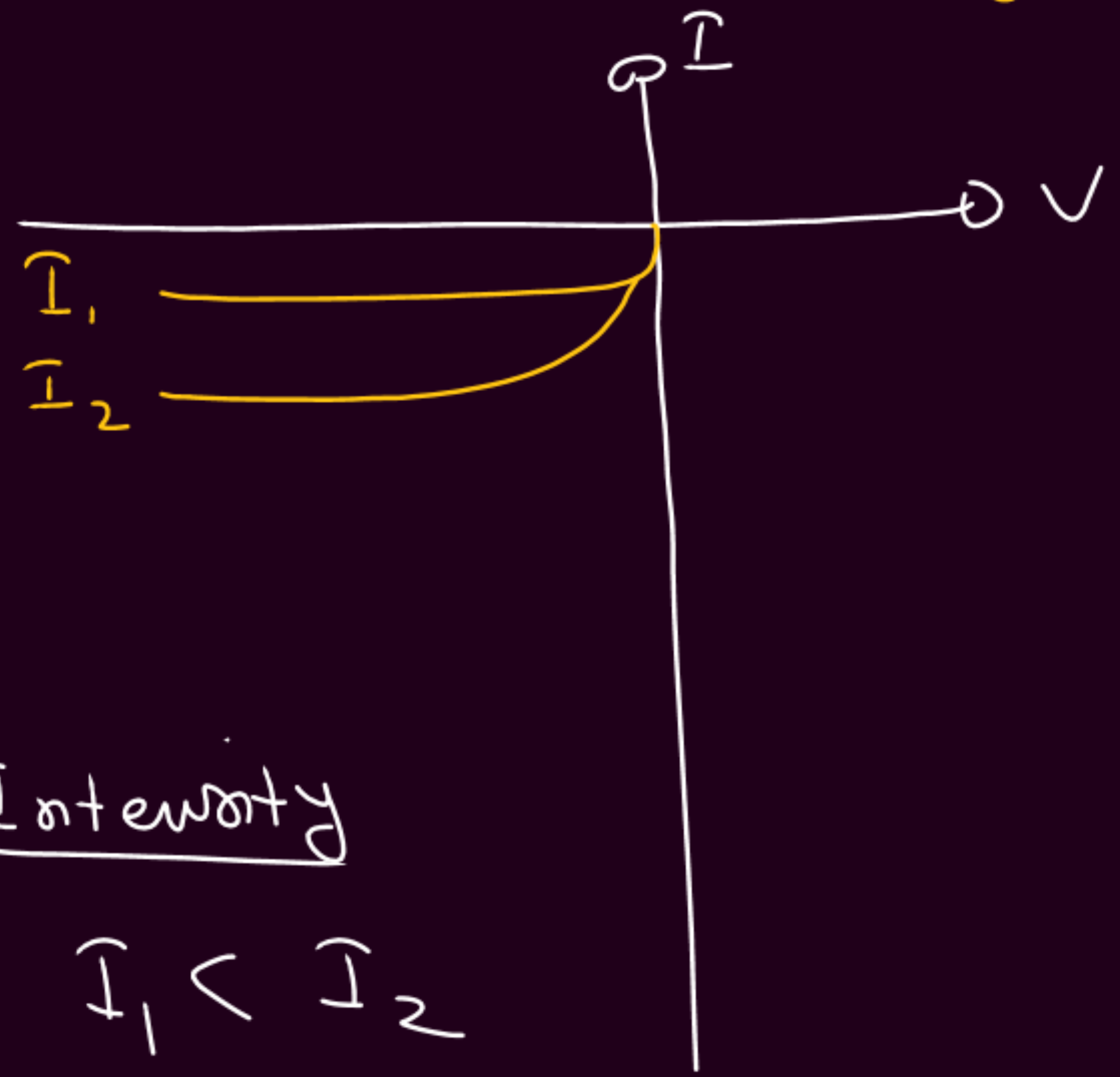
↳ ↑ the Rate of gen. of e^-h pair

→ Drift ↑

→ Used in R.B.

→ (Reverse i_s) $\propto$ (Intensity)

→ To detect optical signals



Intensity

$I_1 < I_2$

② LED 

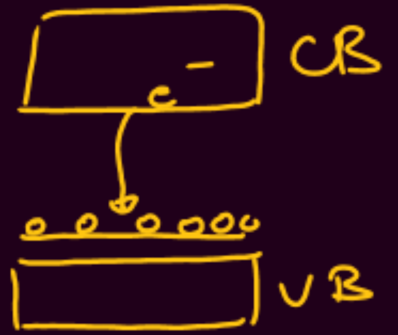
→ Recombination
  ↳ Photon
    ↳ Visible
      ↓
      E_g (1.8eV to 3eV)

→ Forward Bias

→ Heavily Doped

→ Remote Control
  Burglar Alarm

→ E_{ph} is equal to or slightly less than E_g



→ Forward current — Intensity

Small → Small

increase → ↑ then max.

then it ↓

(Recombination → Heat)

→ GaAs (IR)

→ $GaAs_{0.6}P_{0.4}$ (Red)

LED Vs Incandescent Lamp

↳ Low voltage

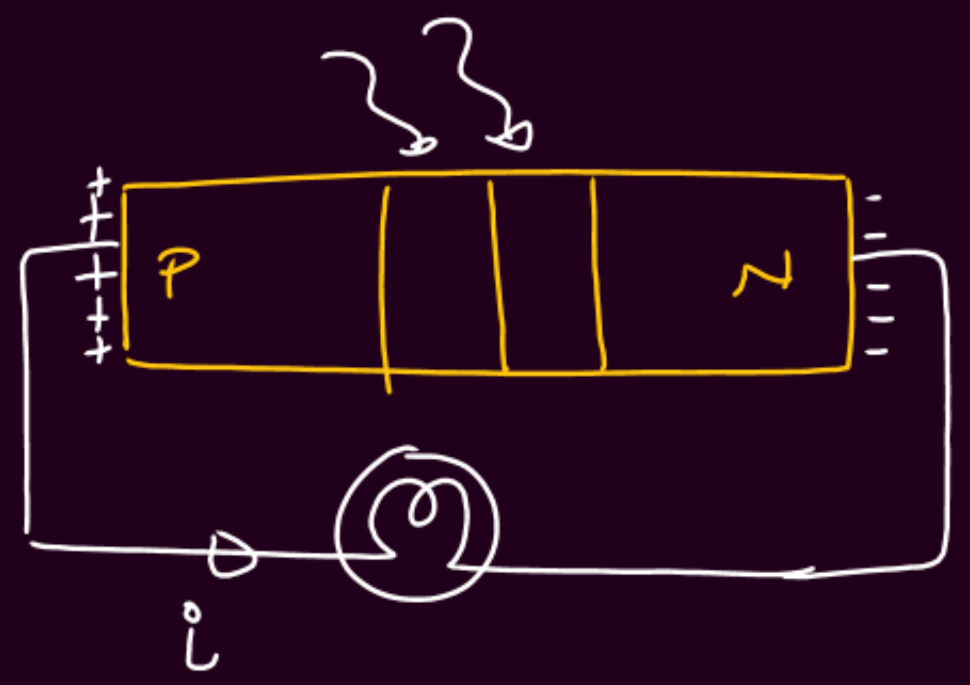
↳ Fast action

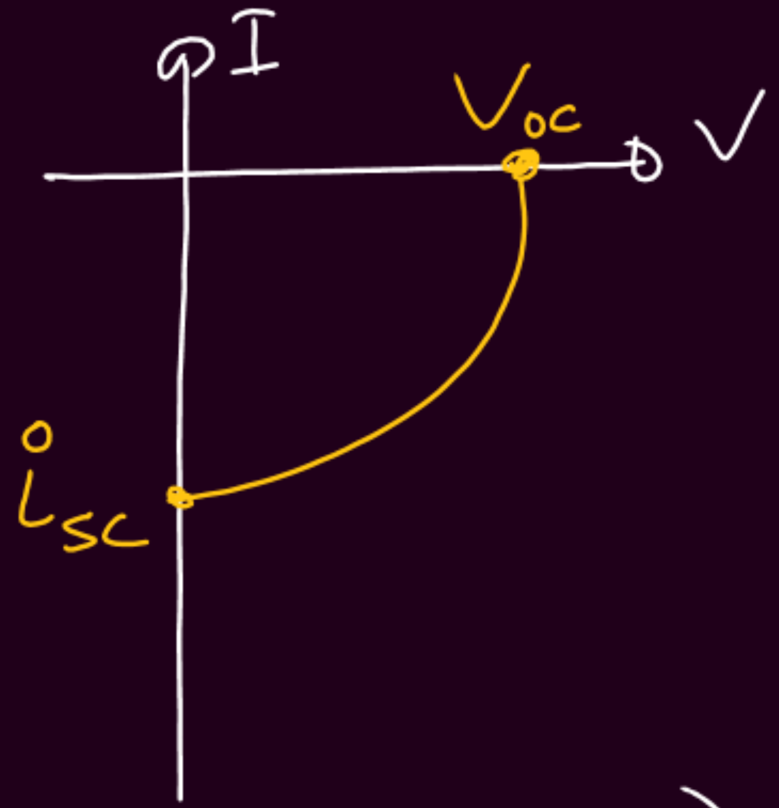
↳ Fast on & off

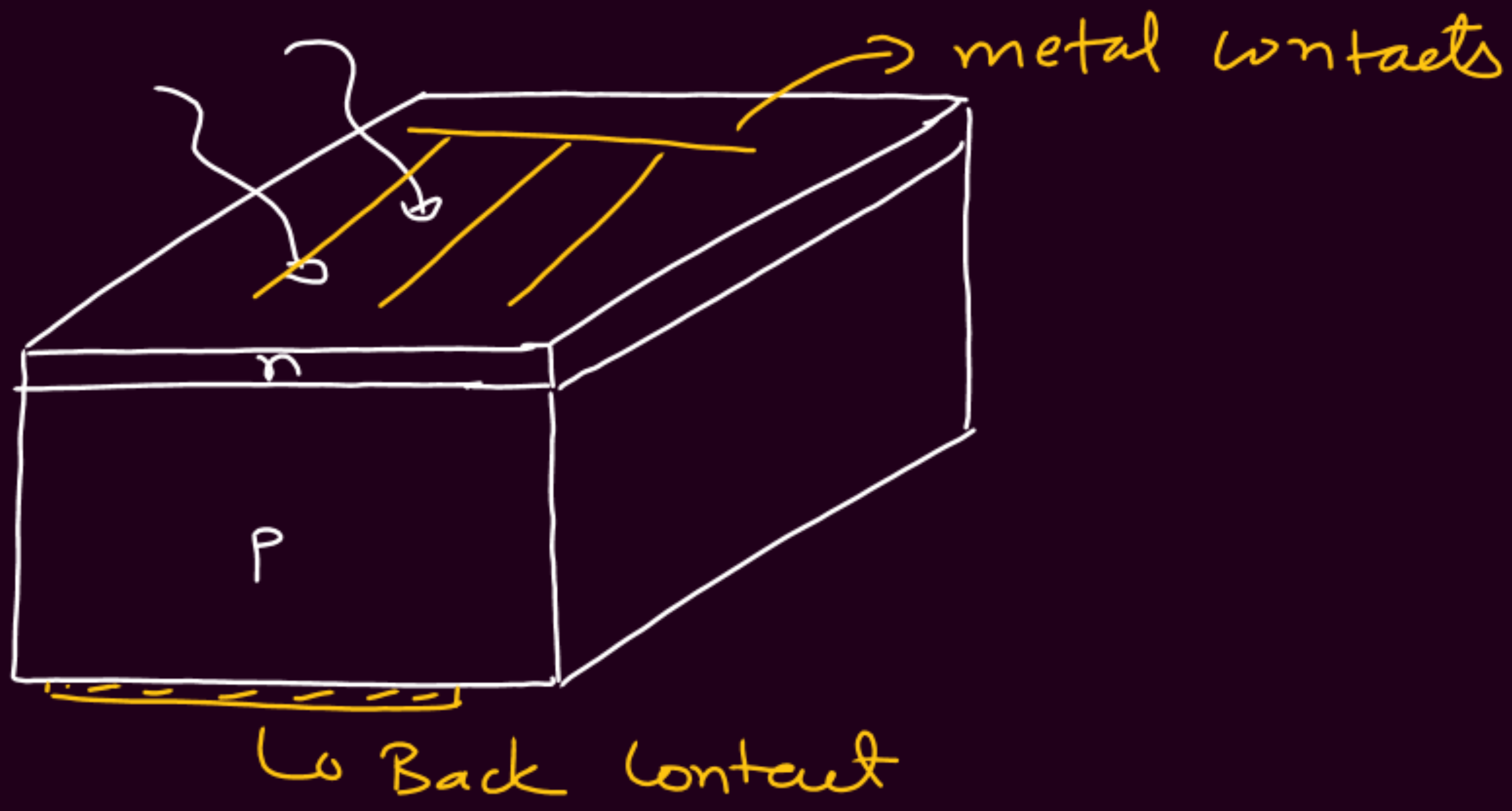
↳ Long life

→ Nearly monochromatic

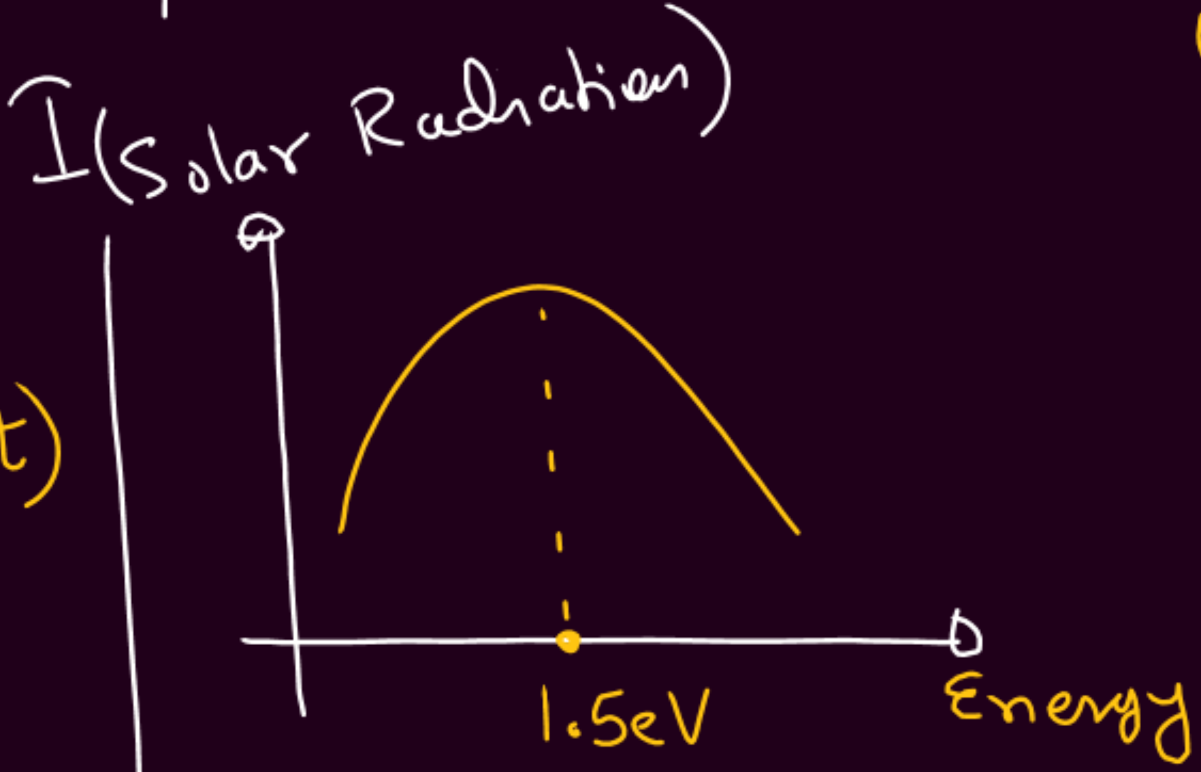
③ Solar Cell







- → generation (e^--h pair)
- → separation ($\vec{E}$ → Drift)
- → Collection

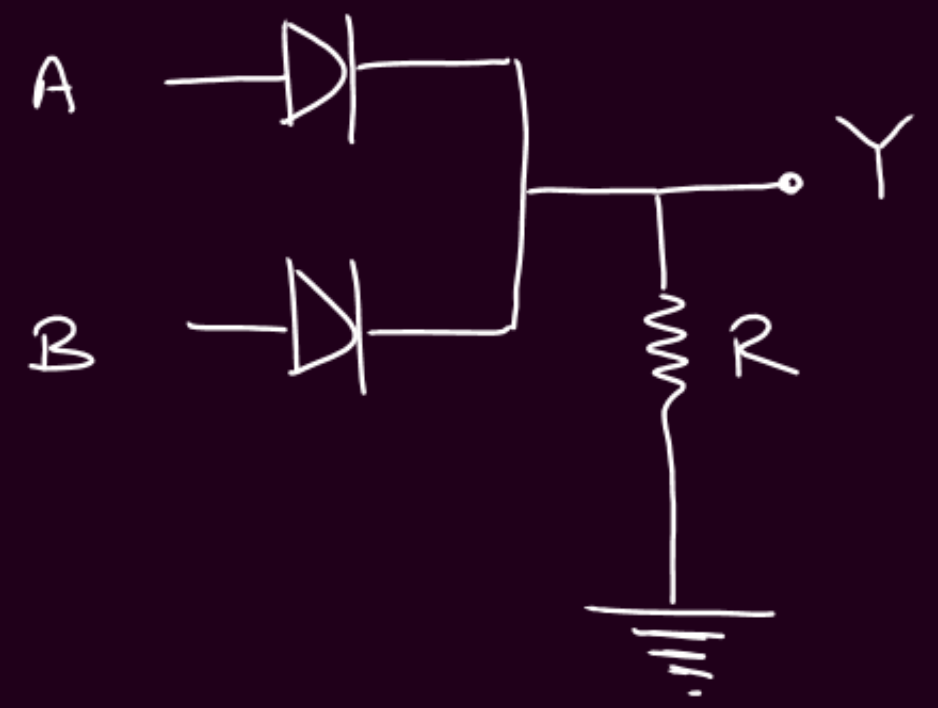


Solar cell → material

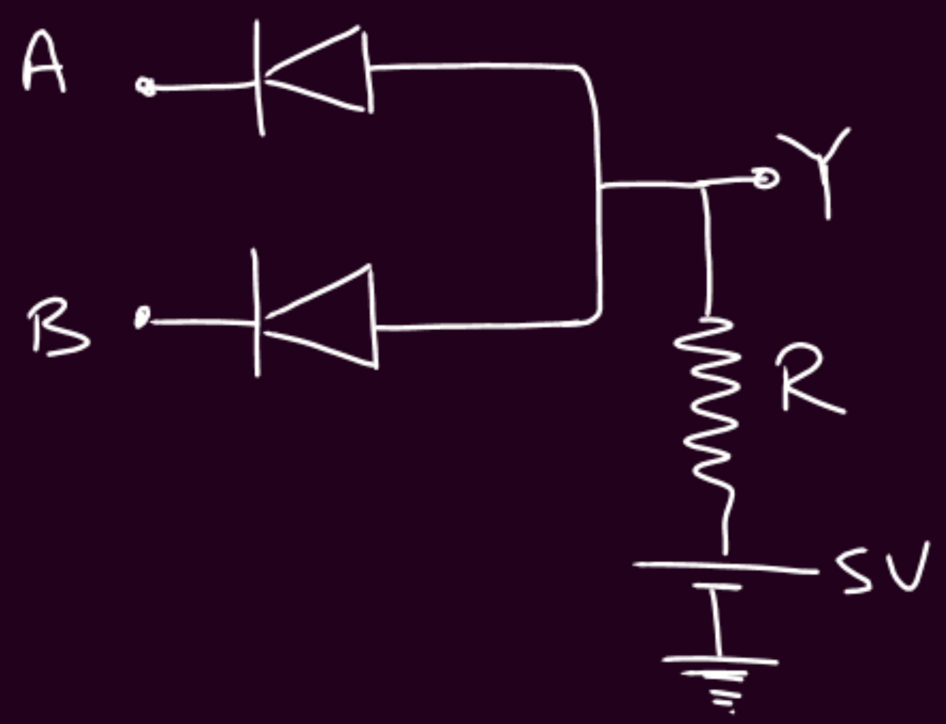
- → E_g (1 to 1.8 eV)
- → High optical Absorption
- → Availability & cost

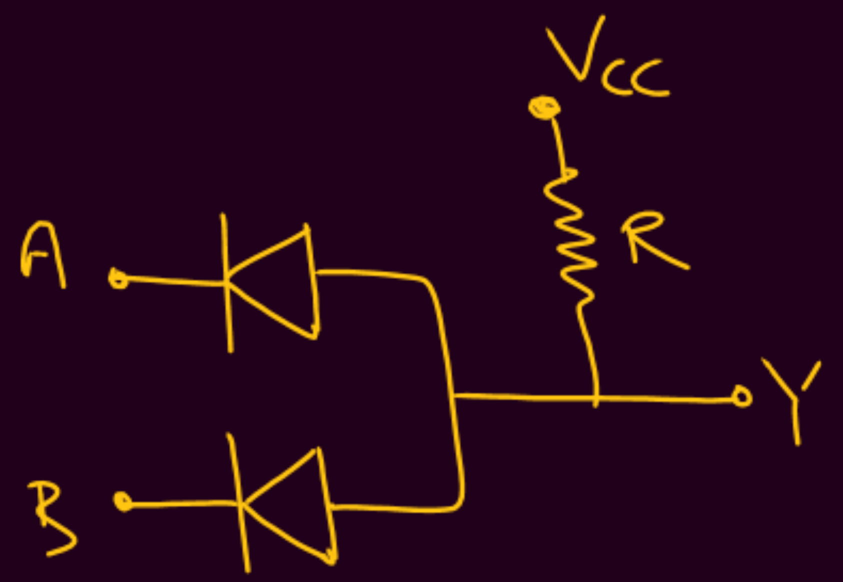
Realisation of Gates

① OR Gate

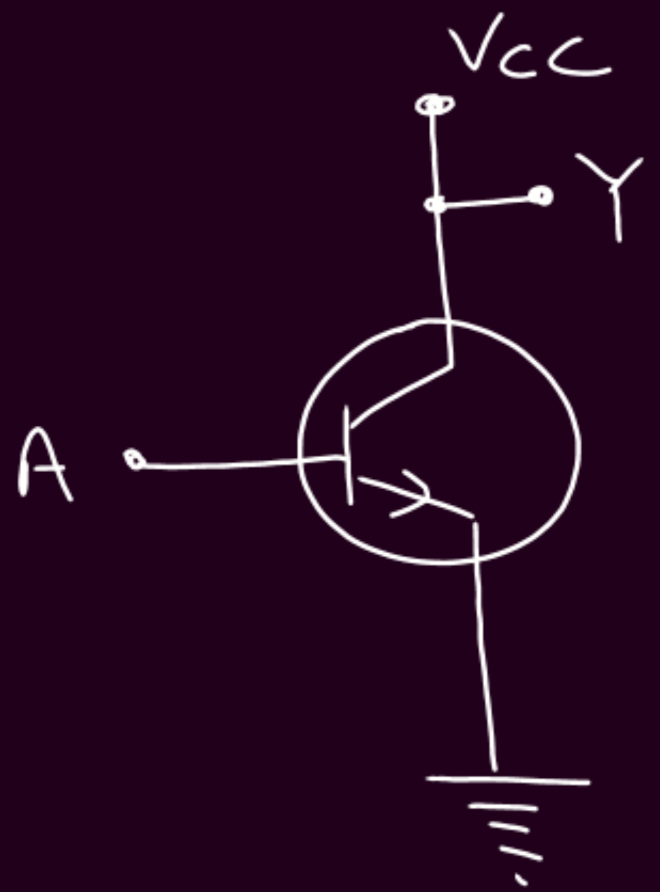


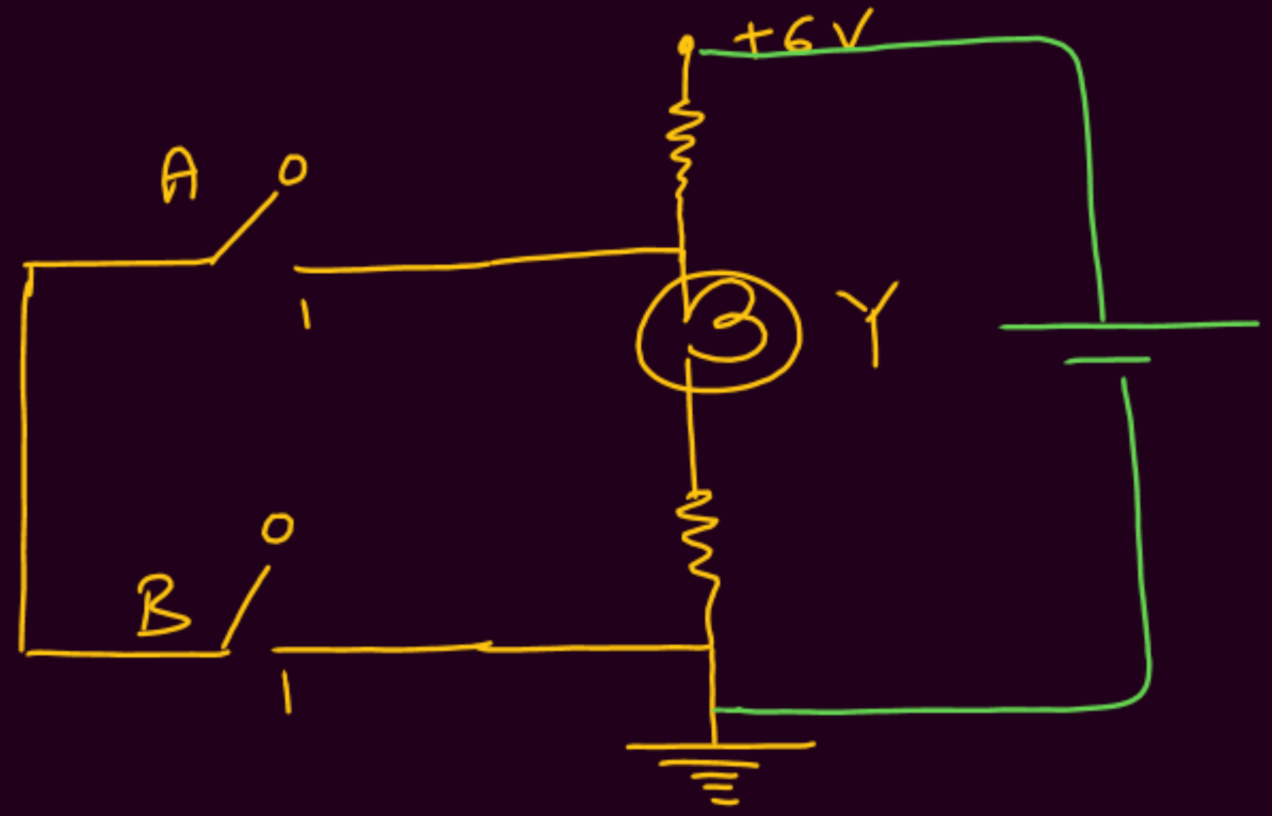
② AND Gate





③ NOT Gate





A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

$\boxed{\text{NAND}}$

$\boxed{\text{short}}$