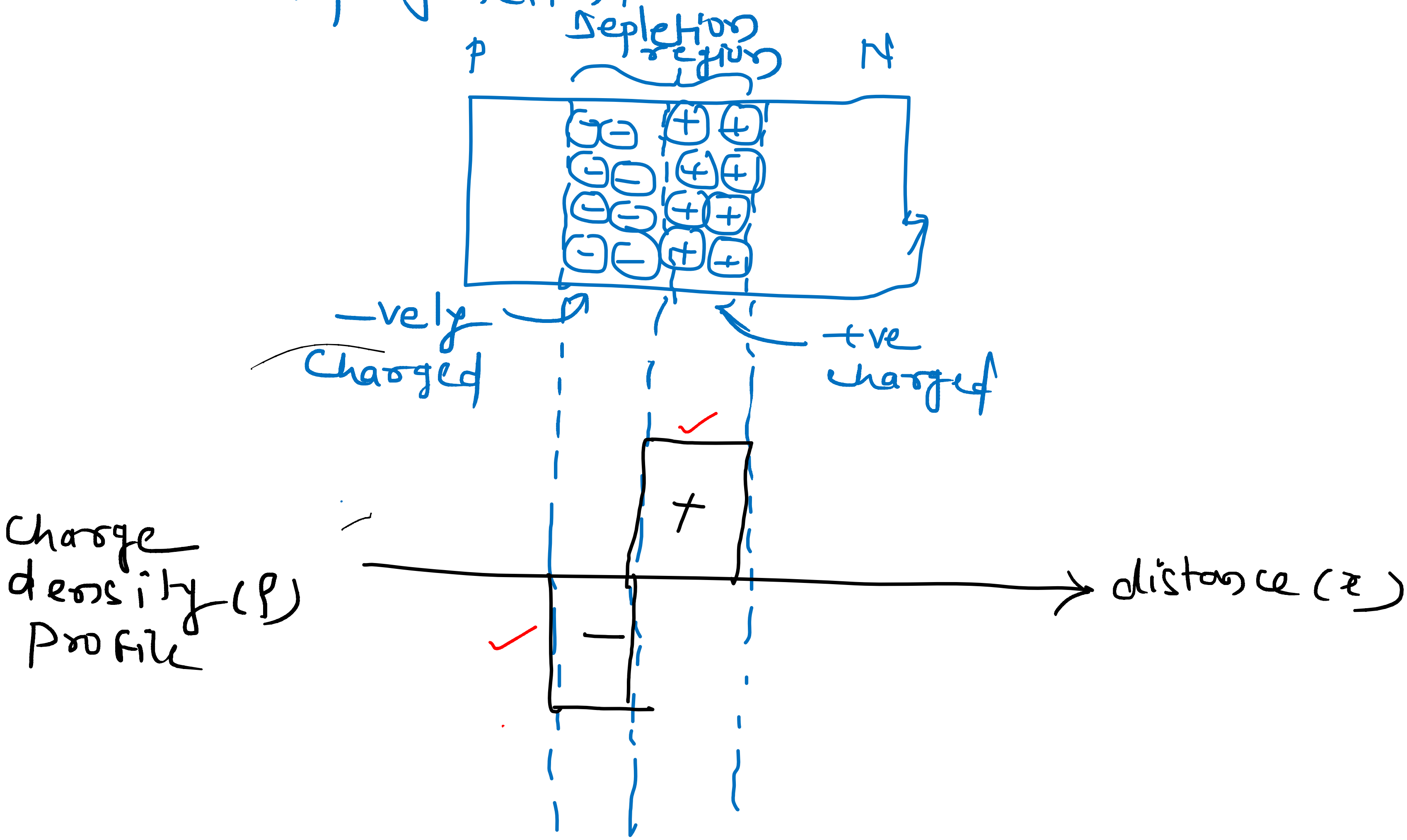
Charge density (ρ), Electric Field intensity (E) & Electrostatic potential (V) profile in PN diode depletion region :-

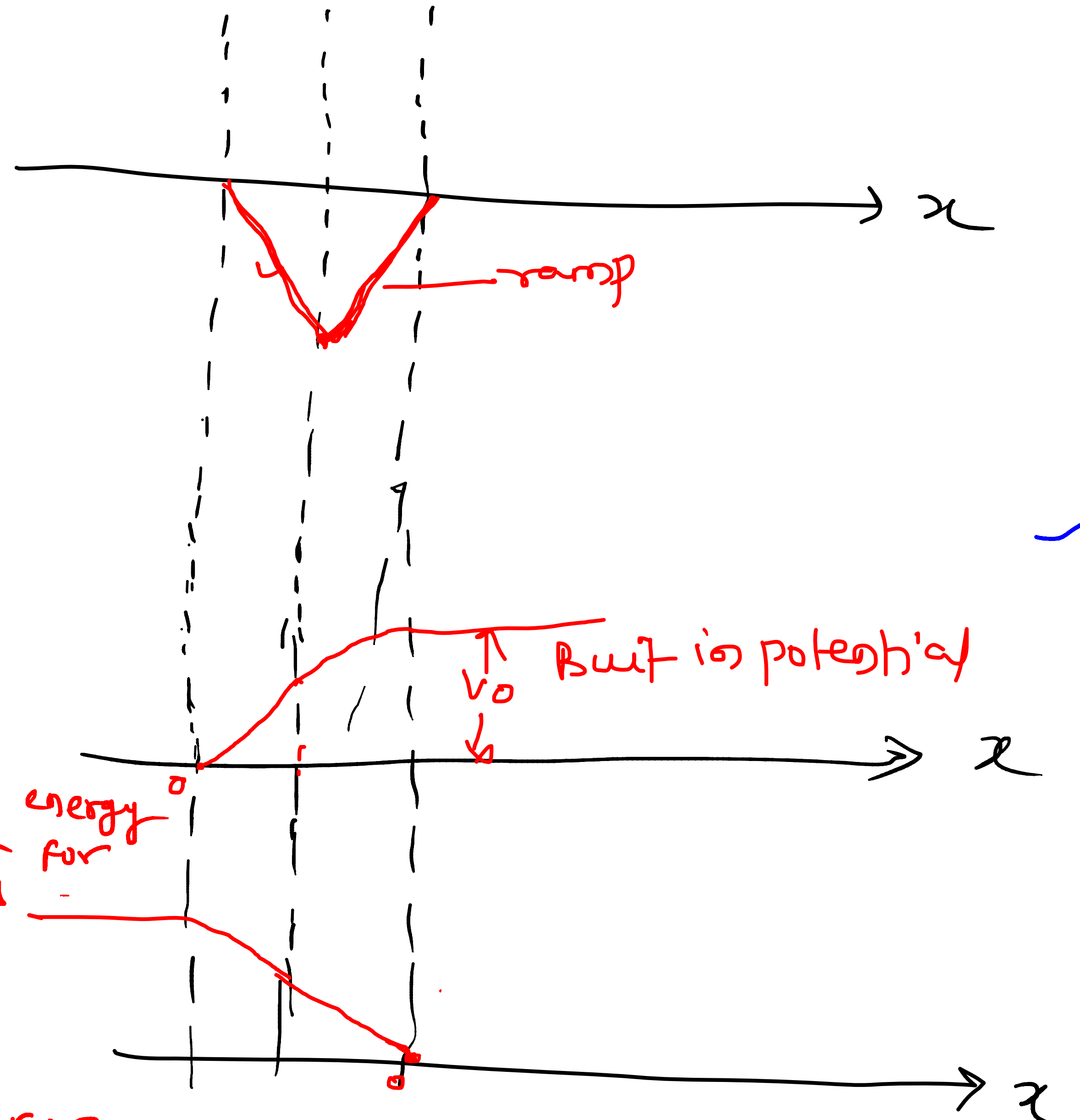
In a step junction :-



$$E = \frac{1}{\epsilon}\int \rho \, dx$$

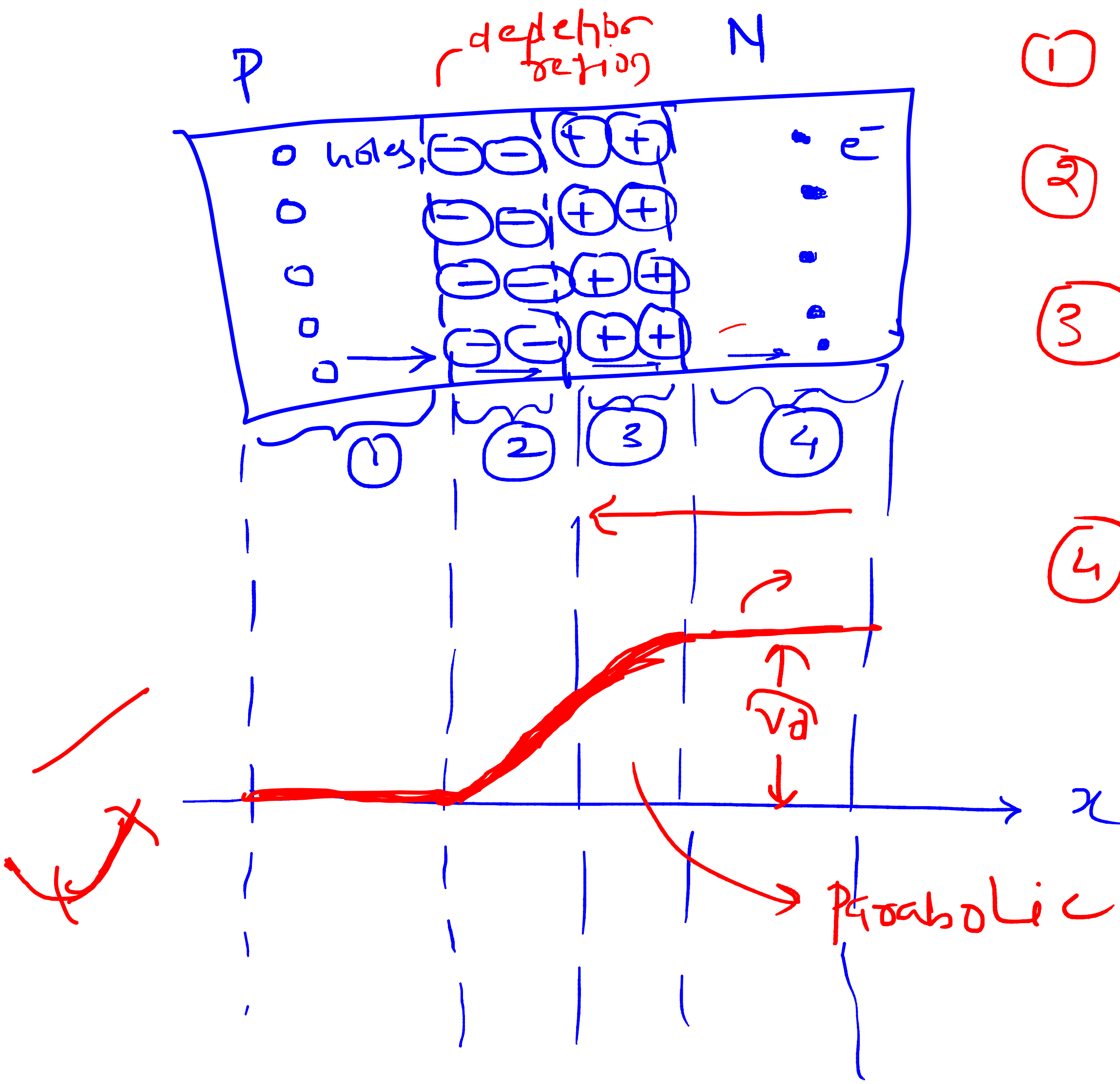
$$E \propto \int \rho \, dx$$

$$V = -\int E \, dx$$



Step function → Ramp function

Ramp function → parabolic function



① No opposition

② minimum opposition for hole.

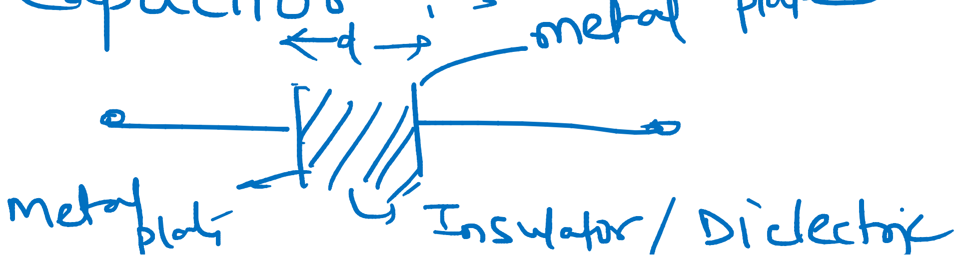
③ Maximum opposition for holes (because of +ve ions)

④ max. opposition for hole & saturation (because of e^- hole recombination in N side)

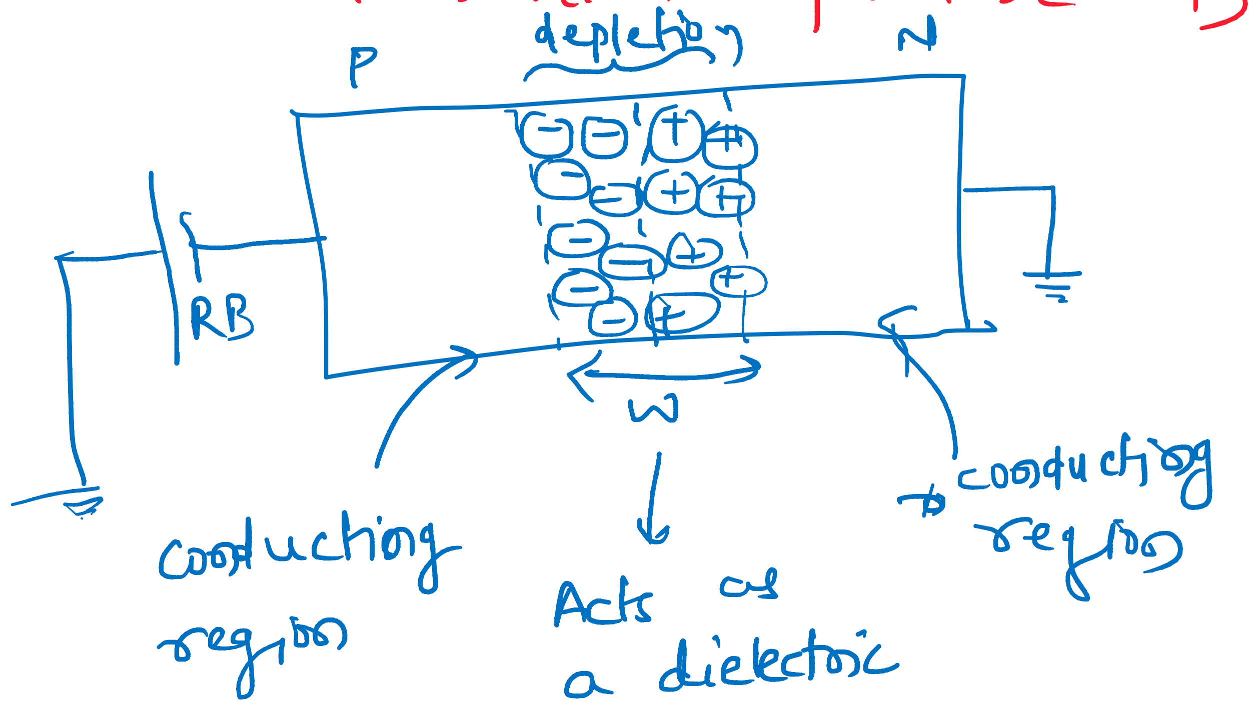
Capacitance in diode

Transition capacitance (C_T)	Diffusion capacitance (C_D)
→ Prominent in reverse bias	→ Prominent in forward bias
→ It is used in the design of variable capacitors.	→ Low resistance $\tau = r C_D$ ↳ low time constant

Parallel plate capacitor :-



Transition capacitance (C_T)



For a parallel plate capacitor $C = \frac{\epsilon A}{d}$

$$C_T = \frac{\epsilon A}{W}$$

ϵA ← Area of PN diode

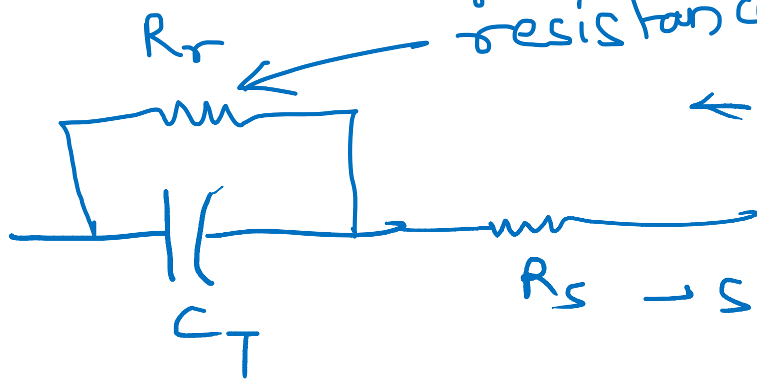
W ← width of depletion region

RB $\uparrow$, $W \uparrow$, $C_T \downarrow$

Used in voltage variable capacitor (varicap)

Symbol

reverse resistance



← equivalent circuit

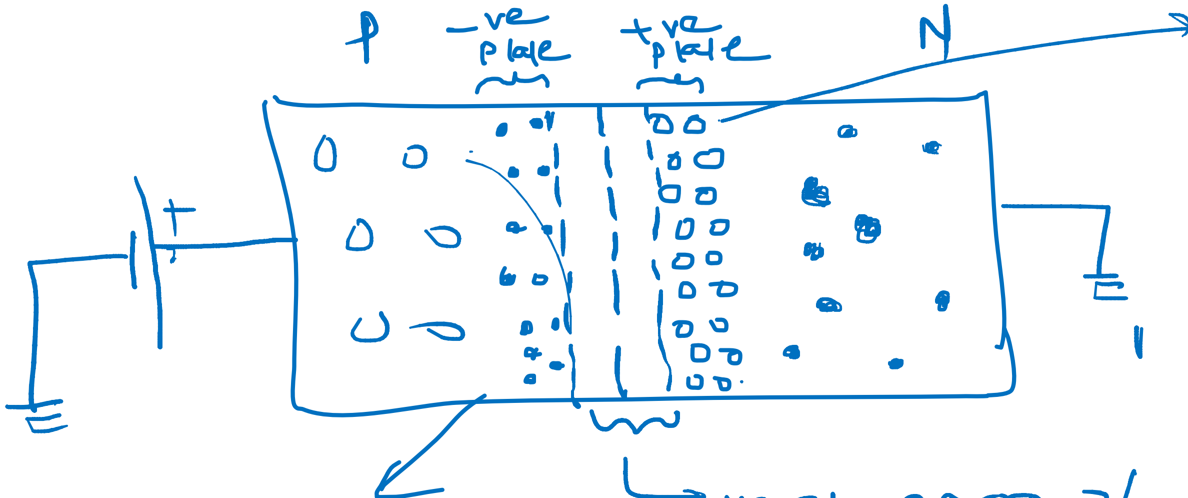
R_s → series resistance

$V_R = 4\,V$, $C_T \approx 20\,pF$

$R_s = 8.5\,\Omega$

$R_r > 1\,M\Omega$

2. Diffusion Capacitance (C_D)



free holes moved to N side trying to recombine with e^- or move to the edge of diode

free e^- moved to the p side & trying to recombine with holes (or) move to the edge of diode

very narrow w/negligible (acts as a dielectric)

$$C_D = \frac{\tau I}{n V_T}$$

τ = Life time of carriers

I = Diode current

n = constant (=1, Ge ; =2, Si)

V_T = Thermal voltage

Lifetime of carriers :- It is the time duration spent by e^- in CB and holes in VB to support conduction before undergoing recombination.

$$\tau_n = \frac{l_n^2}{D_n}$$
lifetime of e^-

$$\tau_p = \frac{l_p^2}{D_p}$$
lifetime of holes

l_n → Diffusion length of e^-

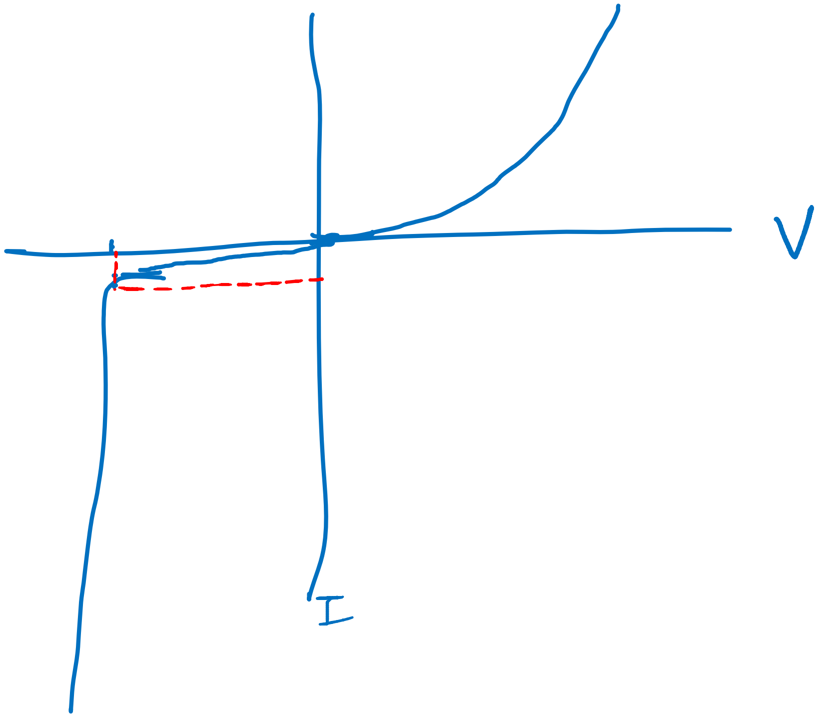
l_p → Diffusion length of holes

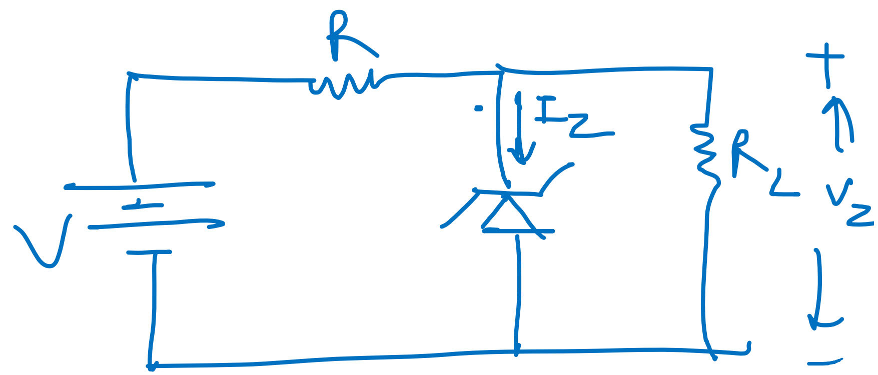
D_n → Diffusion constant of e^-

D_p → Diffusion constant of holes.

CB → conduction band
VB → valence band

I Breakdown diodes





① Breakdown region → RB of PN junction diode

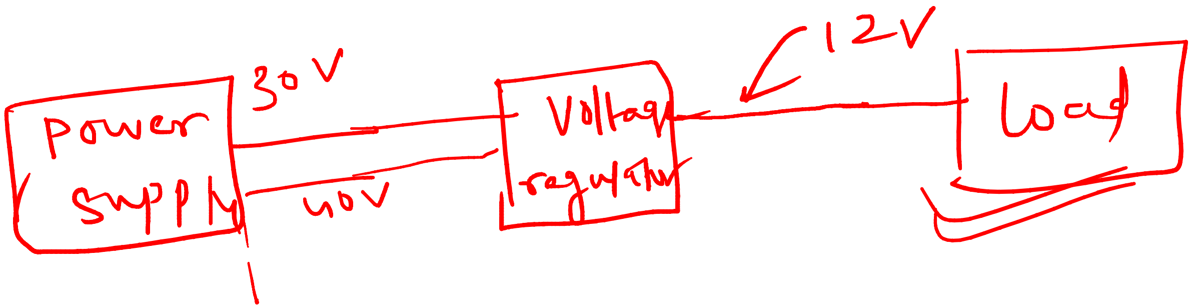
② With proper design → almost constant voltage (diode voltage)

↳ voltage regulator

↳ breakdown diodes

↳ Avalanche diode

↳ Zener diode



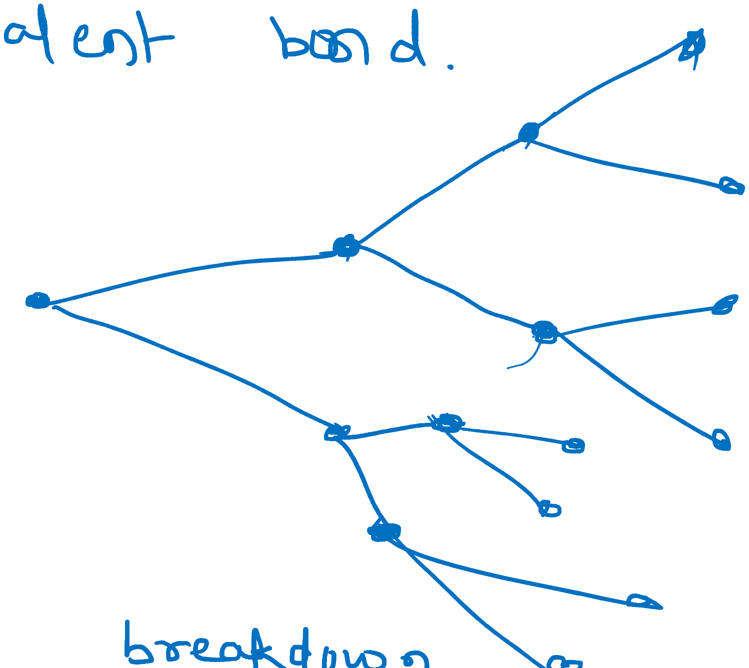
— x —

1. Avalanche breakdown / Avalanche multiplication
2. Zener breakdown

Avalanche multiplication

$V_r \uparrow$, $W \uparrow$, $\oplus \ominus \uparrow$, $E \uparrow$

carriers obtain sufficient kinetic energy to knockout the other atoms and frees the electrons / Holes ~~for~~ by breaking the covalent bond.

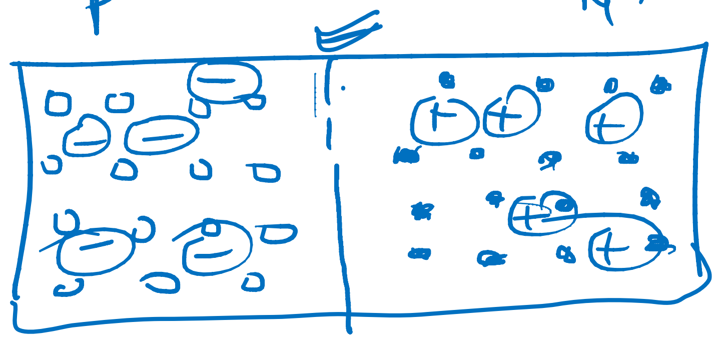


→ Avalanche multiplication

→ Occurs due to impact ionization

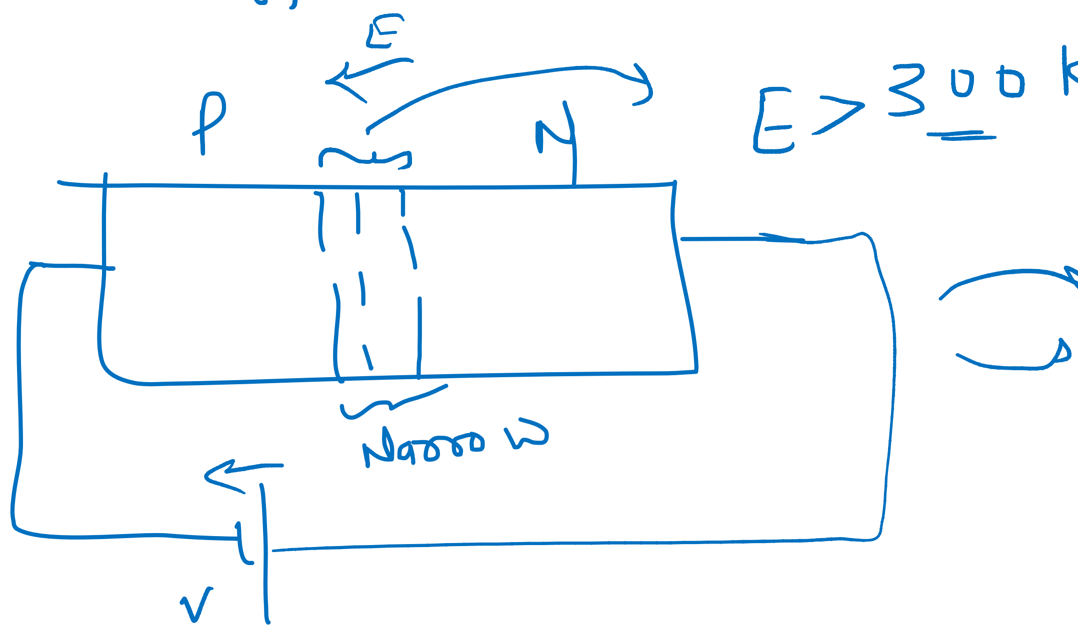
$V_r = V_B \rightarrow$ breakdown voltage

Zener effect



* P, type and N type regions are heavily doped.

* W ↓



$E > 300\ kV/cm$

Avalanche breakdown	Zener breakdown
(1) Not useful & device burns if the current through diode exceeds max. limit of diode.	(1) It is useful and device is safe. Application → voltage regulator
(2) It occurs due to impact ionization.	(2) It occurs due to field ionization.
(3) Occurs in PN diode and in zener diode at high reverse bias.	(3) It occurs in zener diode only.
(4) PN diode usually utilizes a Graded / Linear junction	(4) Zener diode usually utilizes a step junction.
(5) PN diode is relatively less doped	(5) Zener diode is relatively heavily doped.

(6) Breakdown voltage has +ve temperature coefficient.

$$\frac{dV_A}{dT} = +ve$$

(7) Occurs at relatively high reverse bias voltage ($V_A > 6$ V)

(6) Zener breakdown voltage has -ve temp. coefficient.

$$\frac{dV_z}{dT} = -ve$$

(7) Occurs at relatively low voltages. ($V_z < 6$ V)