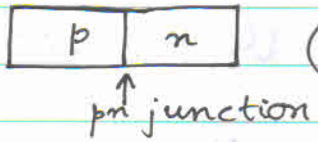
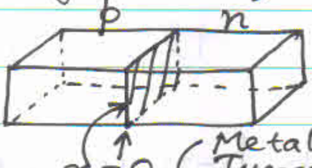
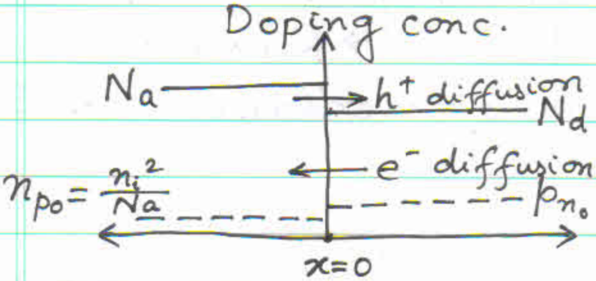
Diode (p-n junction)

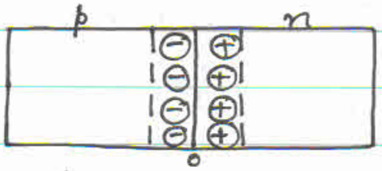
a. 

(Formation)

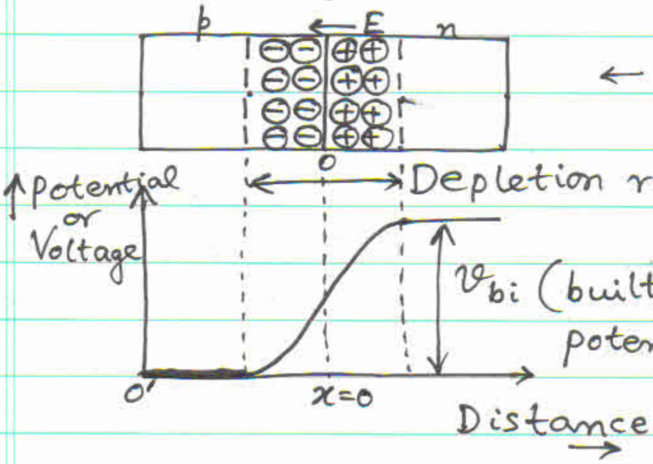




$n_{p0} = \frac{n_i^2}{N_a}$; $p_{n_0} = \frac{n_i^2}{N_d}$



← a) Immediately after joining p & n



← b) Sometime later

Depletion region (or potential barrier reg. or $\underbrace{\text{space charge reg.}}_{\text{Immobile carriers}}$)

v_{bi} (built-in potential)

$$v_{b_i} = \frac{kT}{e} \ln\left(\frac{N_a N_d}{n_i^2}\right)$$; where, $V_T = \frac{kT}{e}$

Thermal voltage (~26mV @300°K)

Built-in potential forms due to the electric field around the junction without any external applied V.

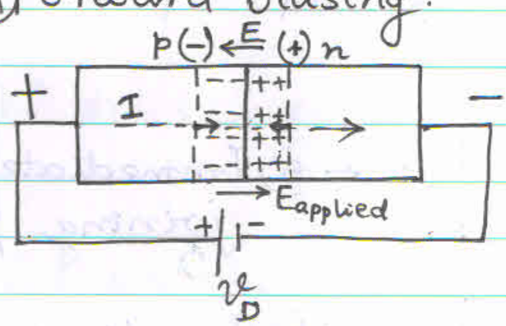
Thermal equilibrium occurs while the force due to E-field & force due to density gradient equalizes.
(Transport of carriers due to drift ≈ Transport due to diffusion)

$$V_{bi}(Si) \approx 0.7V \quad \& \quad V_{bi}(Ge) \approx 0.3V$$

b. p-n junction biasing → Forward / → Reverse

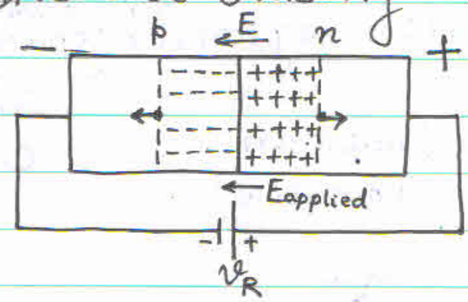
↓ Application of an external V or E-field.

i) Forward biasing (FB):



1. Depletion width reduces
2. FB junction allows passage of current.

ii) Reverse biasing (RB):



1. Depletion width increases
2. RB junction forms a capacitance
3. RB junc^n restricts/stops flow of current.

$$C_j = C_{j_0}\left(1 + \frac{V_R}{V_{bi}}\right)^{-\frac{1}{2}}$$

C_{j_0}: Capacitance at zero voltage (applied)

c. Diode equation:

$$i_D = I_S\left[e^{\frac{v_D}{nV_T}} - 1\right]$$

I_S: RB saturation I ($I_{S(Si)} \cong 10^{-15}$ to 10^{-13})

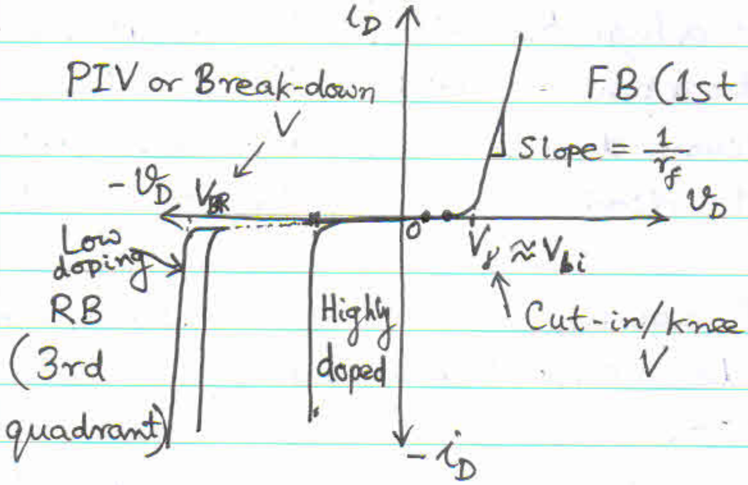
n: Emission co-efficient (1 to 2)

V_T: Thermal voltage

v_D: Applied forward voltage across a diode.

d. Diode symbol:

e. V-I characteristics:



r_f = Forward diode Resistance.

PIV: Peak Inverse Voltage (break-down V)
↳ In RB only

f. Breakdown in diodes → RB
← Under a large E, co-valent bonds break & $e^- - h^+$ pairs are formed → high I-flow → Heat

Avalanche	Zener
A large RB Voltage causes carriers (e^- or h^+) to cross the depletion region with a high kinetic energy, which results in breaking of co-valent bonds & collision. Additional bonds are broken & more collision occurs.	Due to sufficiently doped p-n diode & adequate RB voltage, tunneling of carriers occurs across the junction

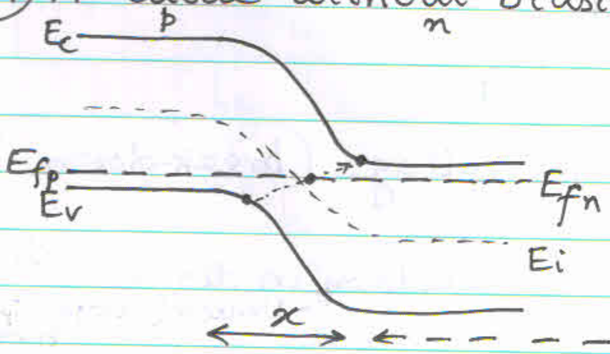
PIV: Max. reverse bias (RB) voltage that may be applied across a diode safely without causing breakdown.

Avalanche	Zener
1) Permanent/unrecoverable breakdown	1) Temporary/recoverable breakdown.
2) Occurs at a high RB voltage	2) Occurs at a lower RB voltage.
3) Relevant to a p-n junc^n with low/medium doping	3) For p-n junc^n with very high doping only.
4) In simple diodes	4) In zener diodes.

g) Band Diagram

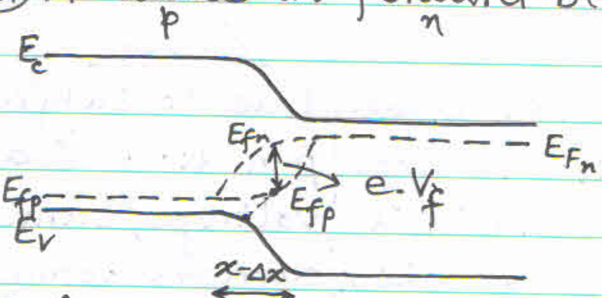
E_f : Fermi energy level → Highest energy state of a carrier in a material at 0 Kelvin (Work done to add an e^- to a sys.)

i) A diode without biasing:

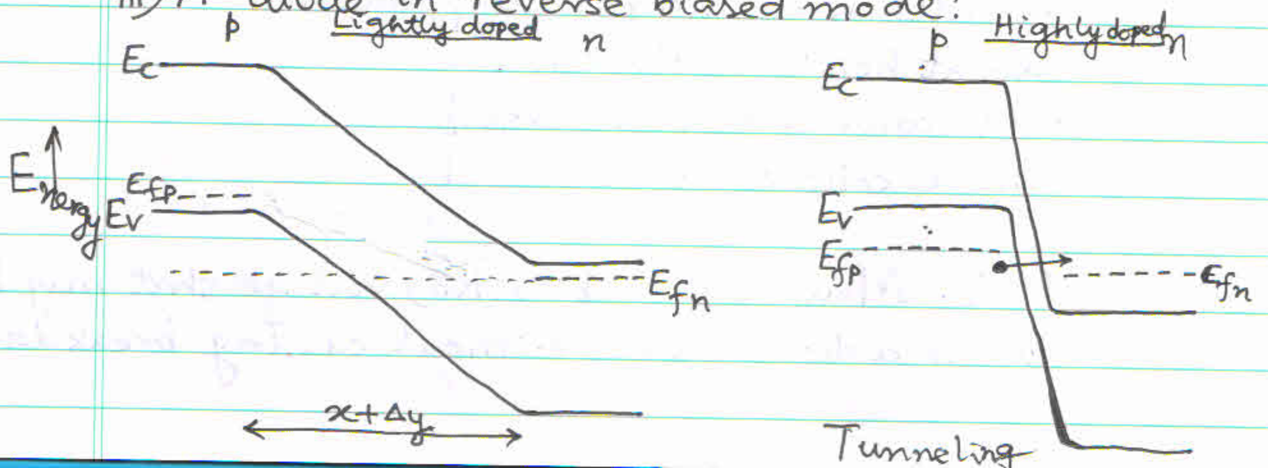


Depletion region

ii) A diode in forward biased mode:

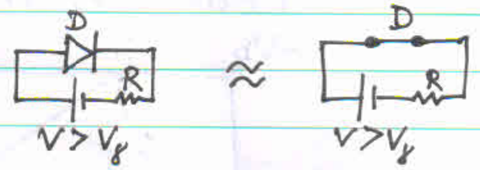


iii) A diode in reverse biased mode:

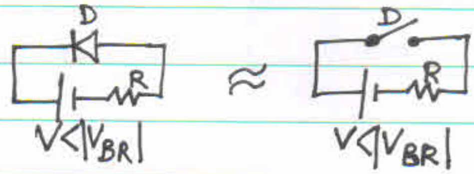


h. Diode as a switch:

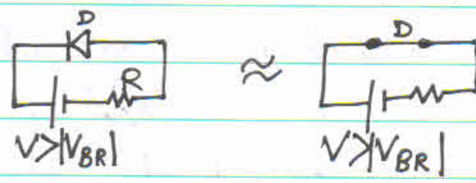
i) Forward Bias: (FB)



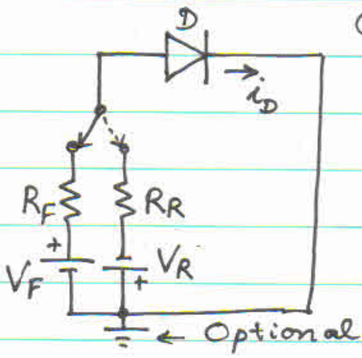
Reverse Bias: (Case 1) (RB)

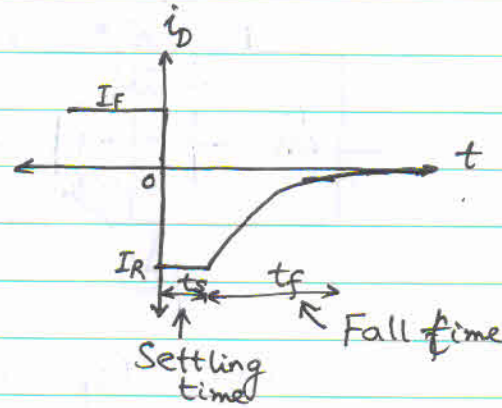


(Case 2)

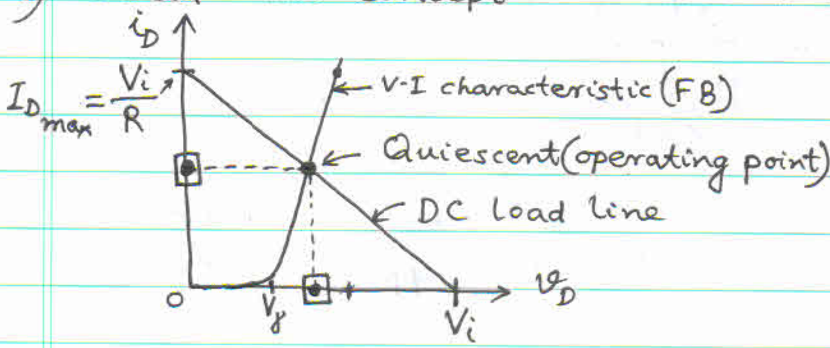


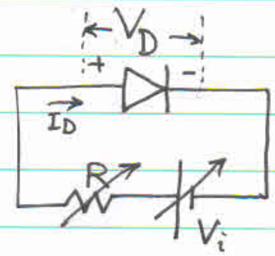
ii) FB & RB switching:





i) Load line concept ⟶ DC & AC



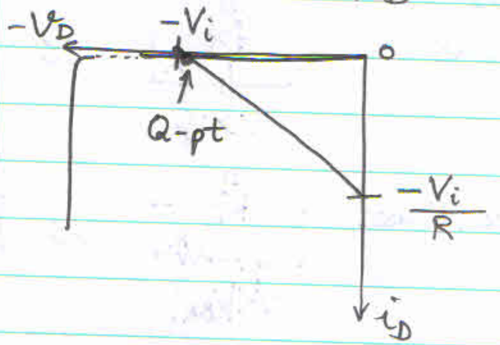


Load line equation: $V_i = I_D . R + V_D$

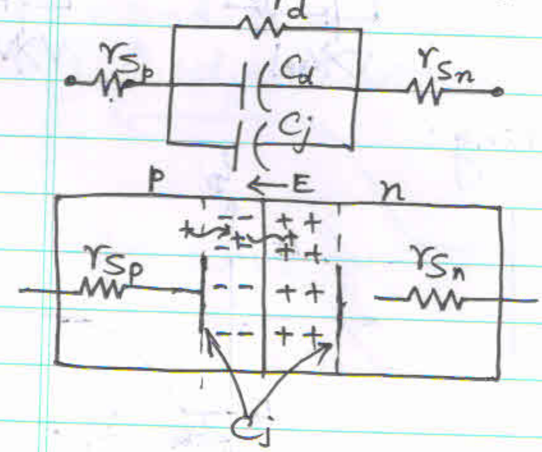
where, $V_D = V_\gamma + I_D . r_f$

(power) $P_D = I_D . V_D$

Load line in RB



j. Equivalent ckt. of a diode: Small signal



$C_d = \frac{dQ}{dV_D}$ (Diffusion C)

r_{S_x} = S-C resistance

C_j = Junction C

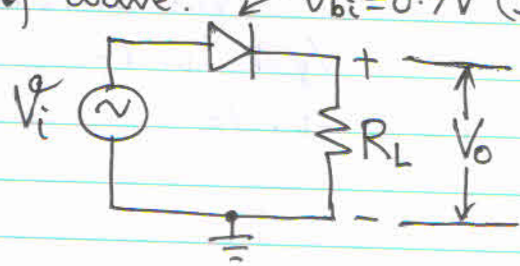
r_d = Diffusion R (junction)

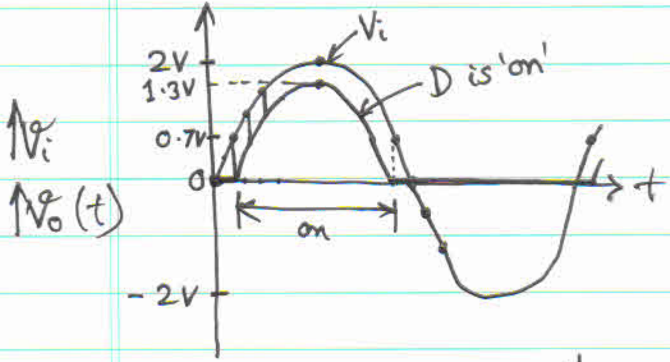
$r_f \approx r_{Sp} + r_{Sn} + r_d$

k. Rectifiers: → AC to DC converter

- Half wave (1-diode)
- Full wave
  - 2-diodes (Center-tapped)
  - 4-diodes (Bridge)

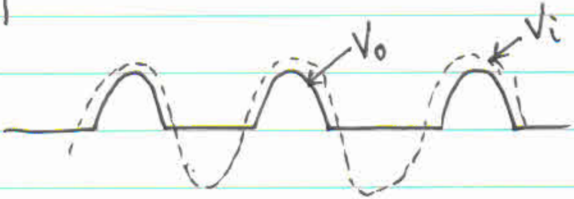
Half wave: $V_{bi} = 0.7V$ (Si)





$$V_i = \overset{I_D \cdot R_D}{V_R} + V_D$$

$$V_i = V_o + V_D$$



Transfer func^n curve