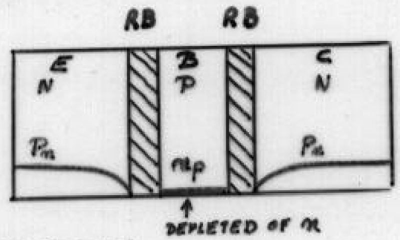
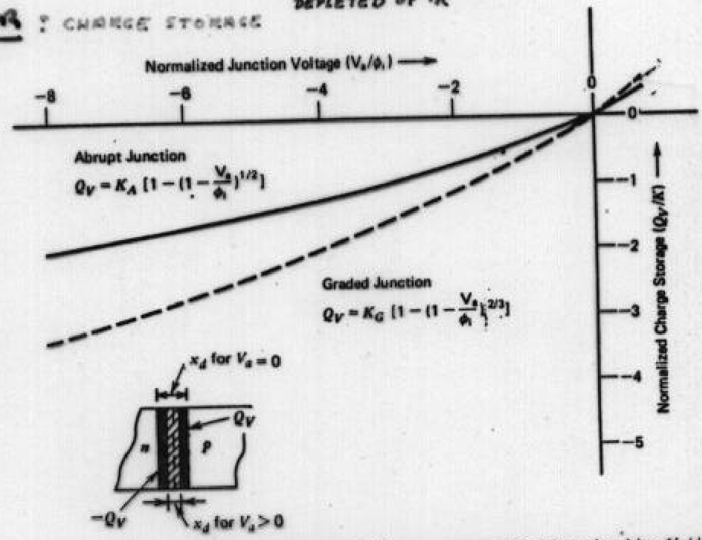
TRANSISTOR SWITCHING: STORAGE, EXTRACTION AND TRANSPORT OF $\bar{e}$ IN THE BASE

CUT-OFF



CAPACITOR: CHARGE STORAGE

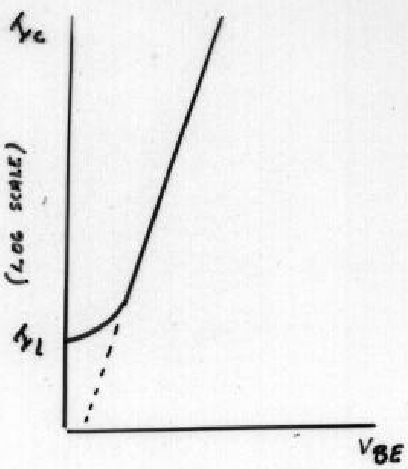


$$K_A = (2\epsilon_s q N_A \phi_i)^{1/2}$$

$$K_G = \frac{1}{8}(12\,\epsilon_s \phi_i (qa)^2)^{1/3}$$

Figure 6.8 Normalized stored charge Q_V/K versus normalized junction bias V_A/ϕ_i in the space-charge regions of an abrupt junction and a linearly graded junction.

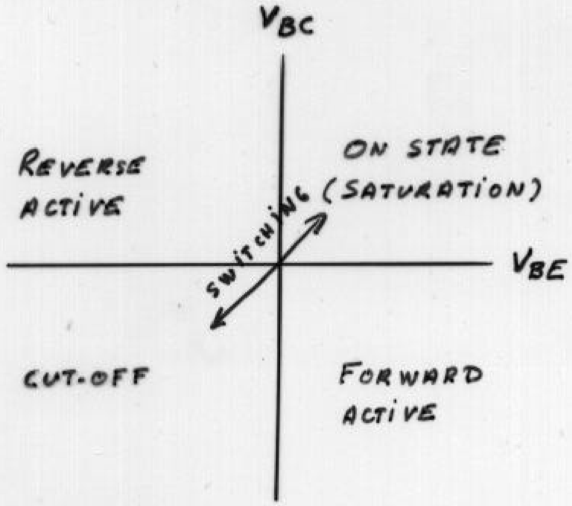
CUT OFF IS NOT AN OPEN-CIRCUIT



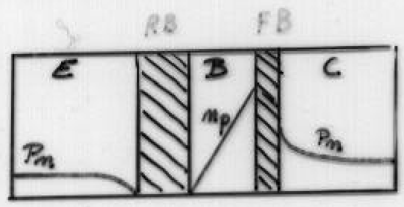
I_l: GENERATION OF HOLES AND ELECTRONS IN COLLECTOR JUNCTION SPACE CHARGE REGION

$$I_l = J_l A_c = I_g = \frac{1}{2}\,\frac{q\, n_i\, x_d\, A_c}{\tau_0}$$

Regions of Operation



Reverse active: parameters: F → R $\beta_R = \left|\frac{\gamma_E}{\gamma_B}\right|$



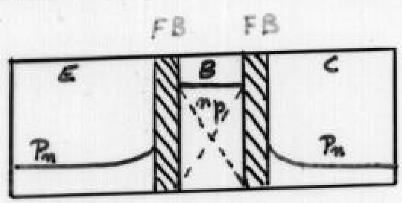
In prototype transistors: symmetric. $\boxed{RA = FA}$

In IC transistors: RA is different from FA

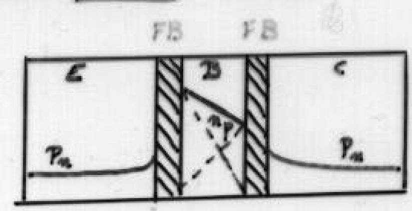
$\boxed{\text{RA performances} \ll \text{FA performances}}$

$\boxed{\beta_R < \beta_F}$

Saturation: each junction injects and collects carriers



No current between E and C

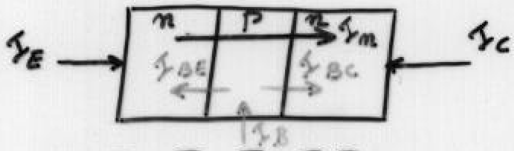


Current flowing from E to C.

EBERS-MOLL MODEL (1954)

LINKING CURRENT: $J_n = J_s\left(e^{\frac{qV_{BC}}{kT}} - e^{\frac{qV_{BE}}{kT}}\right)$

DOES NOT ACCOUNT FOR THE COMPONENTS OF BASE CURRENTS: I_{BE} AND I_{BC}.



$$I_E = I_m - I_{BE}$$
$$I_C = -I_m - I_{BC}$$

$$\left\{\begin{array}{ll} I_m = I_s\left(e^{\frac{qV_{BC}}{kT}} - e^{\frac{qV_{BE}}{kT}}\right) & I_s = J_s A \\ I_{BE} = I_{OE}\left(e^{\frac{qV_{BE}}{kT}} - 1\right) & \text{- EMITTER JUNCTION} \\ I_{BC} = I_{OC}\left(e^{\frac{qV_{BC}}{kT}} - 1\right) & \text{- COLLECTOR JUNCTION} \end{array}\right.$$

$$I_E = -(I_s + I_{OE})\left(e^{\frac{qV_{BE}}{kT}} - 1\right) + I_s\left(e^{\frac{qV_{BC}}{kT}} - 1\right)$$
$$I_C = -(I_s + I_{OC})\left(e^{\frac{qV_{BC}}{kT}} - 1\right) + I_s\left(e^{\frac{qV_{BE}}{kT}} - 1\right)$$

WITH

$$I_{ES} = I_s + I_{OE} \qquad I_{CS} = I_s + I_{OC}$$
$$\alpha_F = \frac{I_s}{I_{ES}} \qquad \alpha_R = \frac{I_s}{I_{CS}}$$

$$\left.\boxed{\begin{array}{l} I_E = -I_{ES}\left(e^{\frac{qV_{BE}}{kT}} - 1\right) + \alpha_R I_{CS}\left(e^{\frac{qV_{BC}}{kT}} - 1\right) \\ I_C = -I_{CS}\left(e^{\frac{qV_{BC}}{kT}} - 1\right) + \alpha_F I_{ES}\left(e^{\frac{qV_{BE}}{kT}} - 1\right) \end{array}}\right\} \text{EBERS-MOLL EQUATIONS}$$

4 PARAMETERS: $I_{ES}, I_{CS}, \alpha_R, \alpha_F$

$$\left.\begin{array}{ll} \text{KIRCHOFF'S LAW} & I_E + I_B + I_C = 0 \\ \text{RECIPROCITY RELATION} & \alpha_R I_{CS} = \alpha_F I_{ES} = I_s \end{array}\right\} \text{TWO ADDITIONAL RELATIONS.}$$

EBERS - MOLL EQUATION

$$I_E = -I_{ES}\left(e^{\frac{qV_{BE}}{kT}}-1\right) + \alpha_R I_{CS}\left(e^{\frac{qV_{BC}}{kT}}-1\right)$$

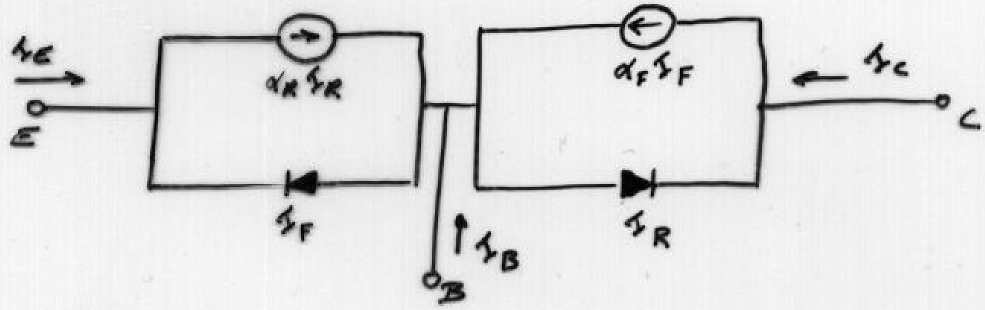
$$I_C = -I_{CS}\left(e^{\frac{qV_{BC}}{kT}}-1\right) + \alpha_F I_{ES}\left(e^{\frac{qV_{BE}}{kT}}-1\right)$$

OR

$$\boxed{\begin{aligned} I_E &= -I_F + \alpha_R I_R \\ I_C &= -I_R + \alpha_F I_F \end{aligned}}$$

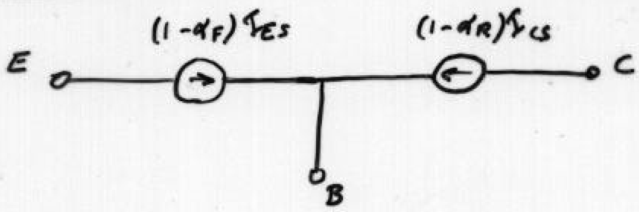
$$\begin{cases} I_F = I_{ES}\left(e^{\frac{qV_{BE}}{kT}}-1\right) \\ I_R = I_{CS}\left(e^{\frac{qV_{BC}}{kT}}-1\right) \end{cases}$$

EQUIVALENT CIRCUIT



$$I_B = -(I_E + I_C) = I_F(1-\alpha_F) + I_R(1-\alpha_R)$$

APPLICATION : CUT-OFF $\quad V_{BE} < 0, \; V_{BC} < 0$



APPLICATIONS

$$\begin{cases} I_E = -I_F + \alpha_R I_R & (1) \\ I_C = -I_R + \alpha_F I_F & (2) \end{cases}$$

IN FORWARD ACTIVE MODE $\qquad \alpha_F \times (1)$ AND REPLACE IN (2)

$$I_C = -\alpha_F I_E - I_R(1-\alpha_F\alpha_R)$$

$$\boxed{I_C = -\alpha_F I_E + I_{CS}(1-\alpha_F\alpha_R)}$$

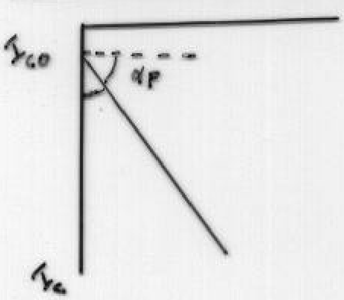
SINCE COLLECTOR IS REVERSE BIASED

IN REVERSE ACTIVE MODE

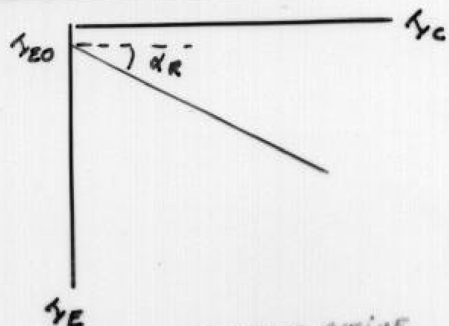
$$\boxed{I_E = -\alpha_R I_C + I_{ES}(1-\alpha_F\alpha_R)}$$

SIMILARILY SINCE EMITTER IS REVERSE BIASED

EXPERIMENTAL DETERMINATION OF α_F, α_R, I_{ES} AND I_{CS}



FORWARD-ACTIVE



REVERSE-ACTIVE

OPEN CIRCUITED EMITTER

$$I_{CO} = I_C\Big|_{I_E=0} = I_{CS}(1-\alpha_F\alpha_R)$$

OPEN CIRCUITED COLLECTOR

$$I_{EO} = I_E\Big|_{I_C=0} = I_{ES}(1-\alpha_F\alpha_R)$$

COMPARISON WITH $\boxed{I_{CEO} = I_E\Big|_{I_B=0}}$

$$I_B = -(I_C + I_E) = 0 \Rightarrow I_E = -I_C$$

$$I_C = +\alpha_F I_C + I_{CS}(1-\alpha_F\alpha_R)$$

$$\boxed{I_{CEO} = \frac{I_{CS}(1-\alpha_F\alpha_R)}{1-\alpha_F}}$$

AMPLIFICATION OF I_{CO}

$$\boxed{I_{CEO} = \frac{I_{CO}}{1-\alpha_F}}$$