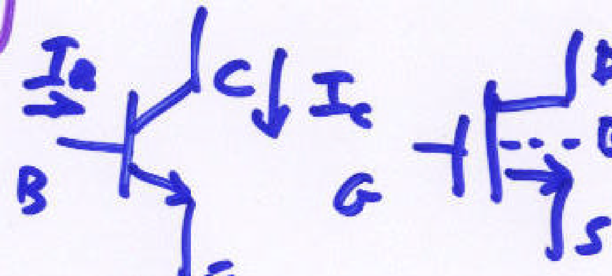
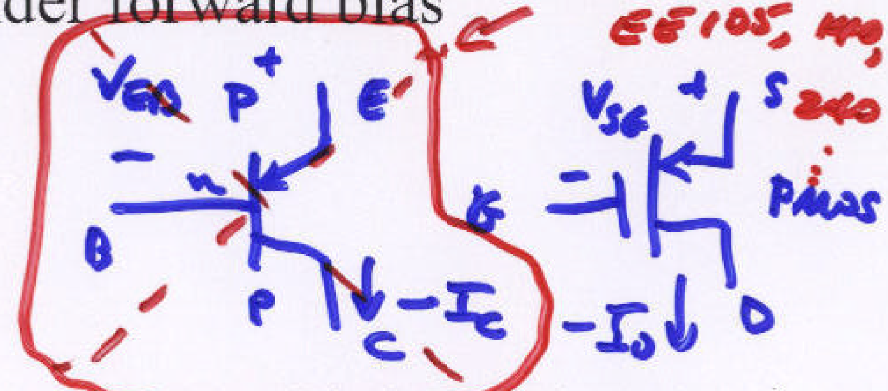
Lecture 20



- Last time:
  - the npn bipolar junction transistor (BJT)
- Today : DEVICE PHYSICS OF BJT
  - Large-signal model under forward bias
  - Ebers-Moll model



PS 7 #1

$$\boxed{I_{DIODE} \ll 1\,\mu A}$$

Why?
[A small
$V_D = 0.65V$.

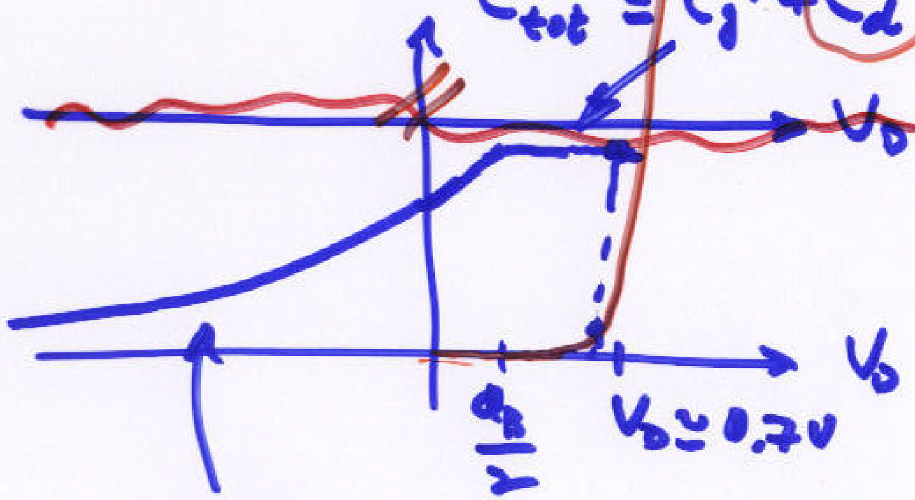
$C_d < C_j$ [unusual ... see problem 2]

I_D/V_{th}

$C_{tot} = C_j + C_d$

$C_d = g_d \cdot \tau_T$

$\left(\frac{1}{r_d}\right)$

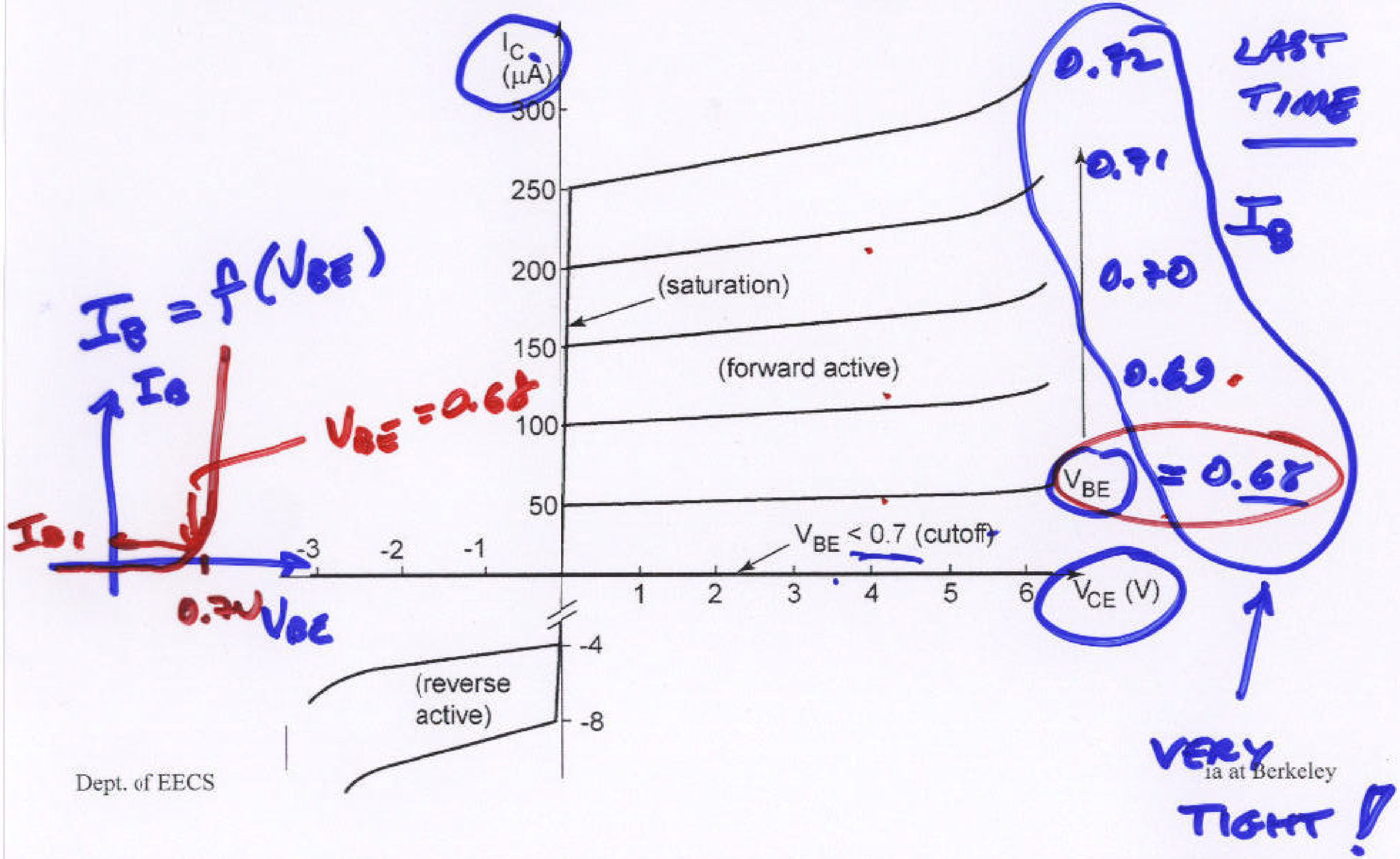


$I_D \propto e^{V_D/V_{th}}$

$$\frac{C_{j0}}{\sqrt{1 - V_D/\phi_B}}$$

R. T. Howe

Base-Emitter Voltage Control

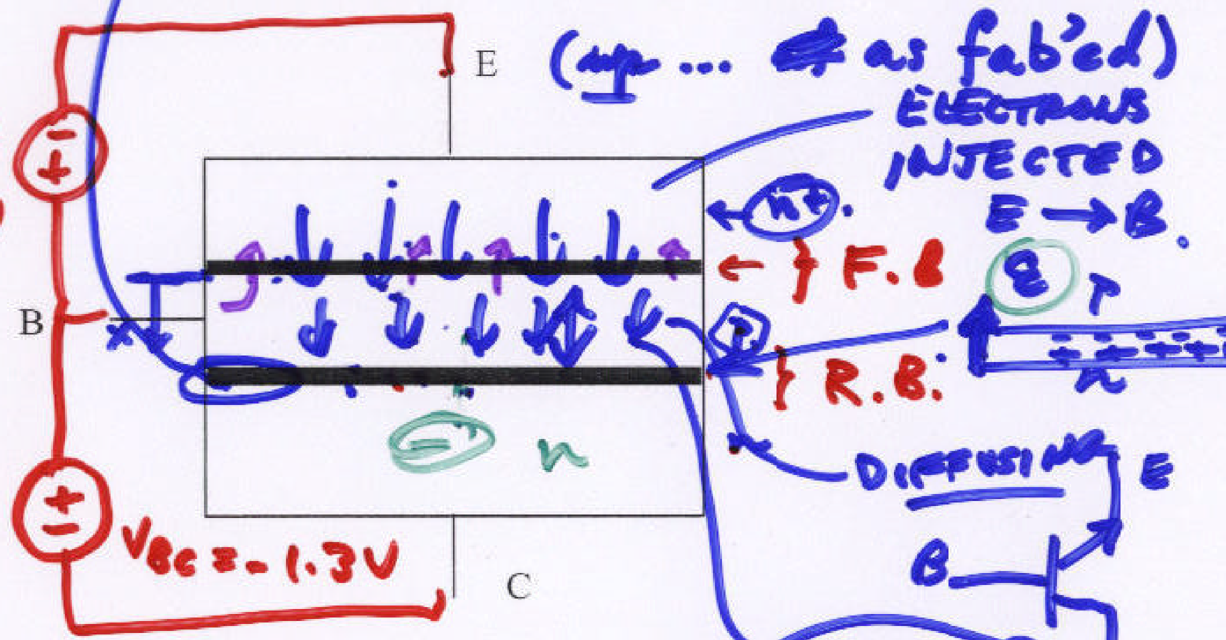


ELECTRONS REACH R.B.'ed BC JUNCTION... "COLLECTED"

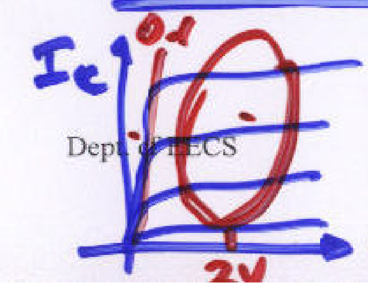
"Transistor Action"

$V_{BC} = -1.3V$

$V_{CB} = 1.3V$

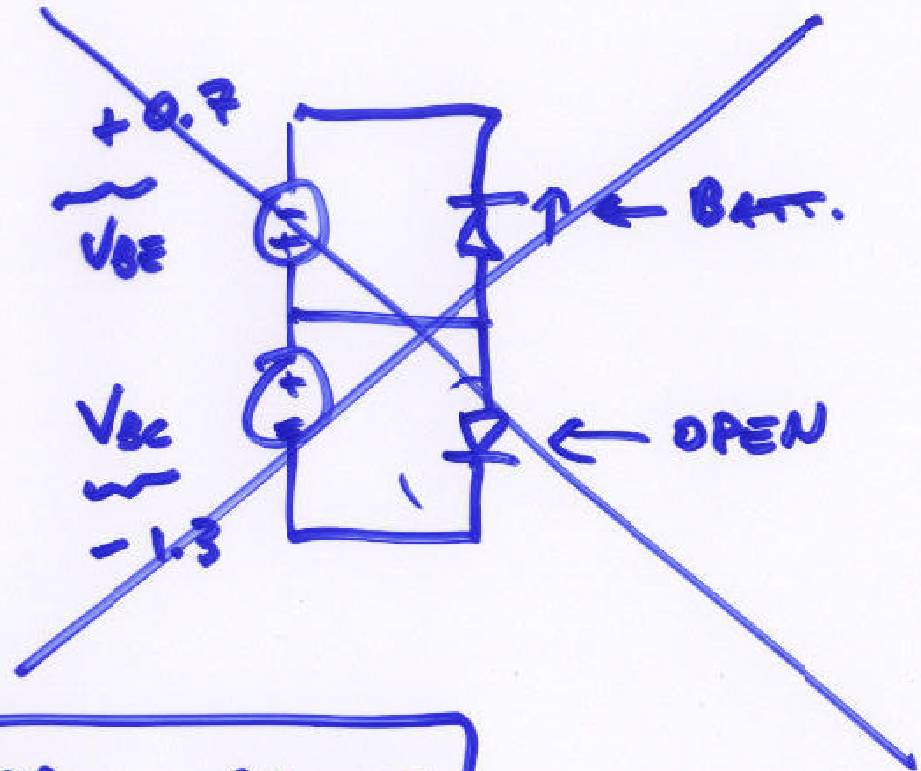


FORWARD ACTIVE ... CONSTANT CURRENT.



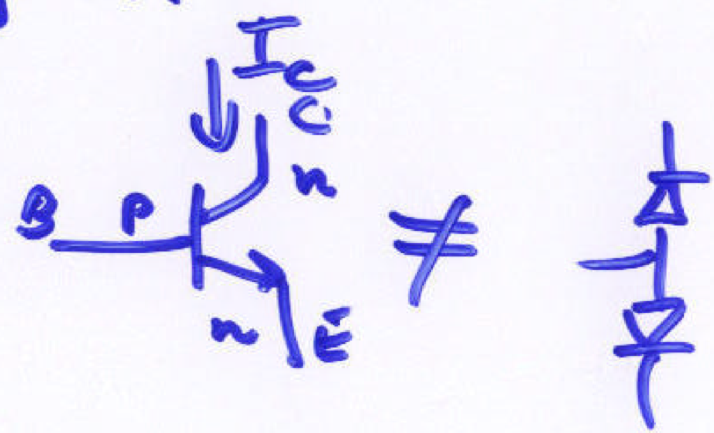
$V_{BE} = 0.7V$ (FORWARD BIASED)

$V_{CE} = 2V$ (EXAMPLE)

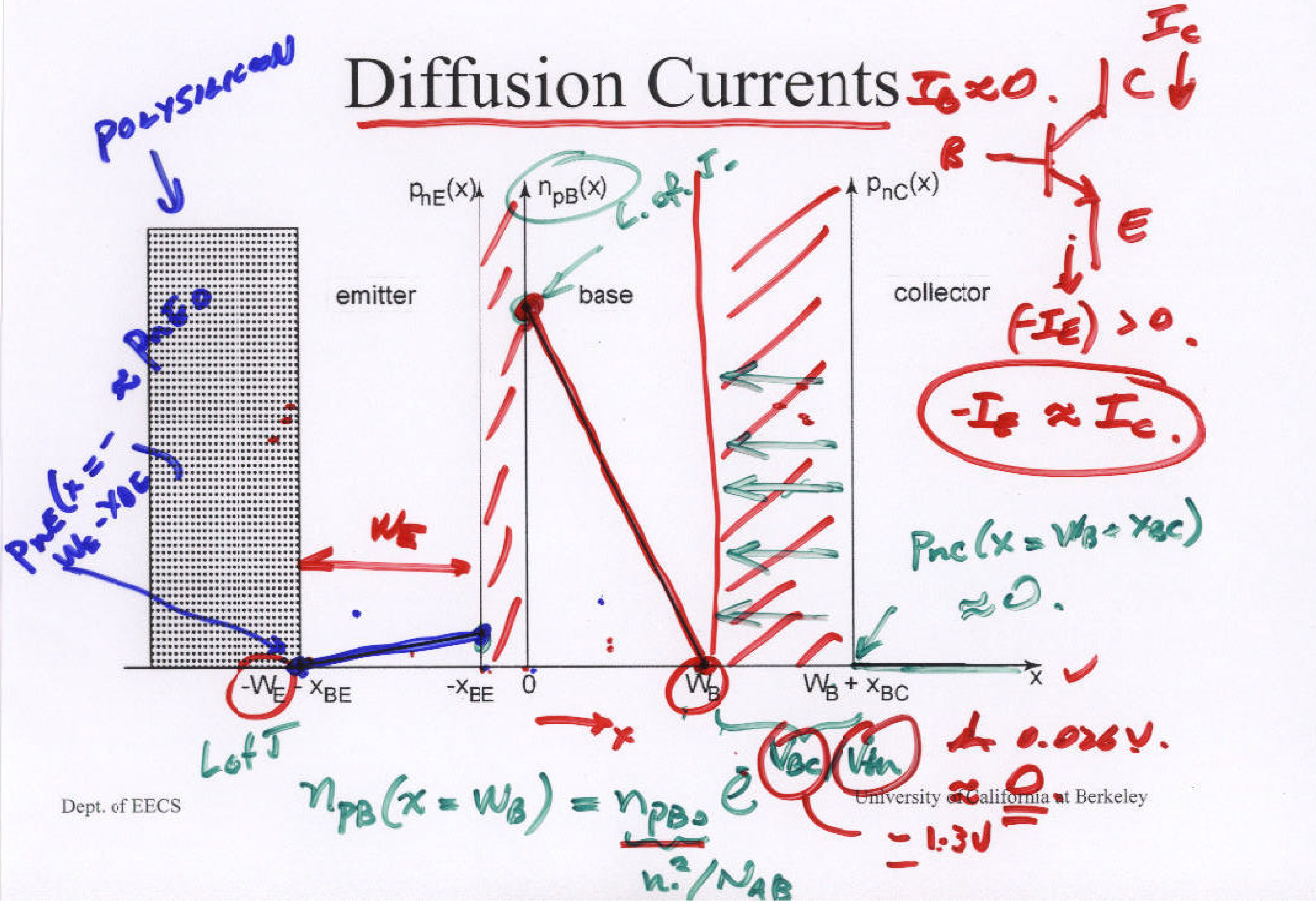


NOBEL PRIZE ....

SEEING THAT



Diffusion Currents



BJT Currents

- Collector current is nearly identical to the (magnitude) of the emitter current … define

"ALPHA-F"

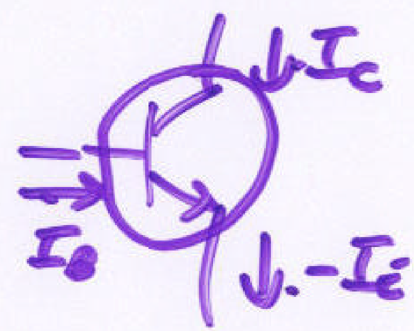
$$I_C = -\alpha_F I_E$$

$$\alpha_F = \frac{I_C}{|I_E|}$$

Kirchhoff: C.L.

$$\alpha_F \approx 0.99.$$

$$-I_E = I_C + I_B$$



DC Current Gain:

$$I_C = \alpha_F(-I_E)$$

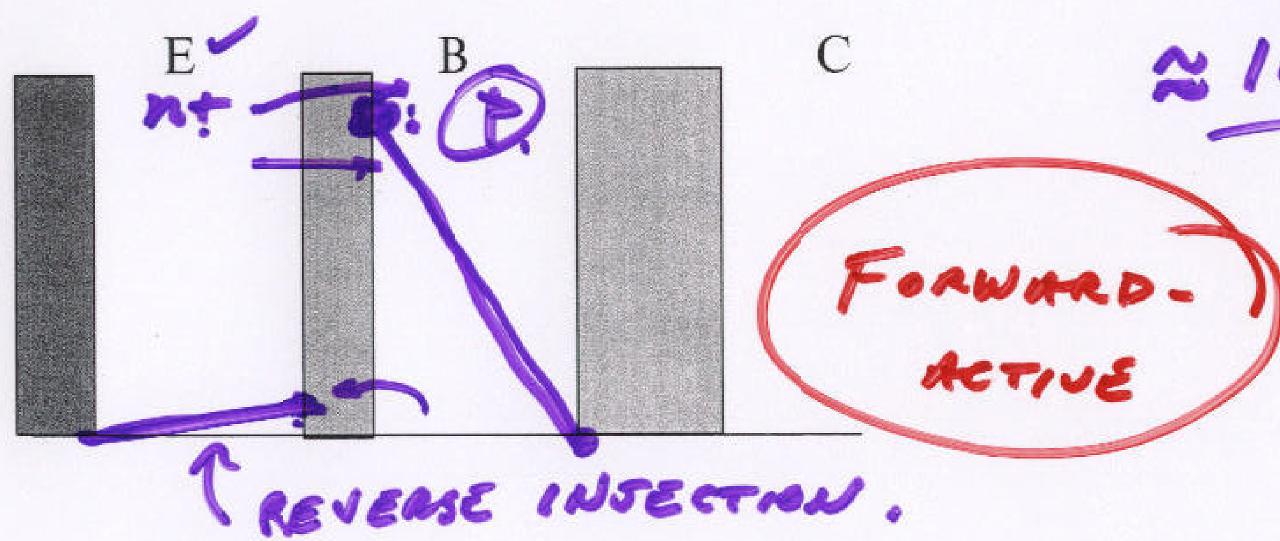
$$= \alpha_F(I_C + I_B) = \alpha_F I_C + \alpha_F I_B$$

$I_C(1-\alpha_F) = \alpha_F I_B$

Origin of α_F

$$I_C / I_B = \frac{\alpha_F}{1-\alpha_F} = \beta_F \approx 100.$$

Base-emitter junction: some reverse injection of holes into the emitter → base current isn't zero



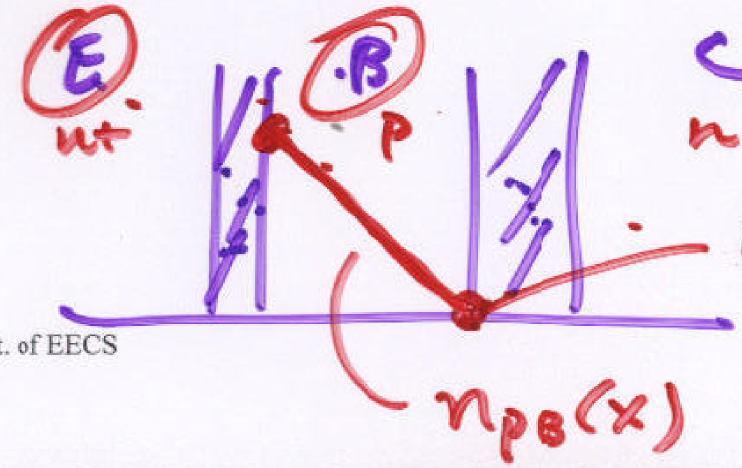
Typical $\alpha_F \approx 0.99$.

Collector Current

Diffusion of electrons across base results in

$$J_n^{diff} = qD_n \frac{dn_p}{dx} =$$

$$I_C = I_S e^{V_{BE}/V_{th}}$$



$$I_C = \left\{ \frac{q D_{nB} n_{pB0} A_E}{W_B} \right\} e^{V_{BE}/V_{th}}$$

$$n_{pB0} = \frac{n_i^2}{N_{aB}}$$

Base Current

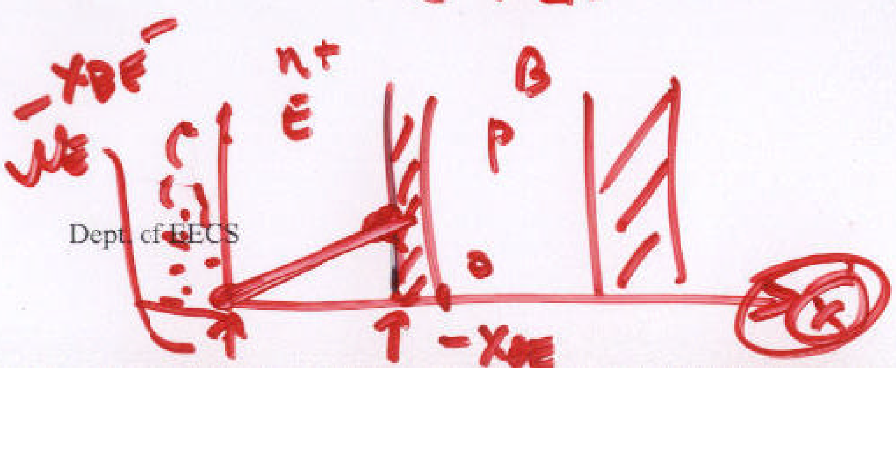
Diffusion of holes across emitter results in

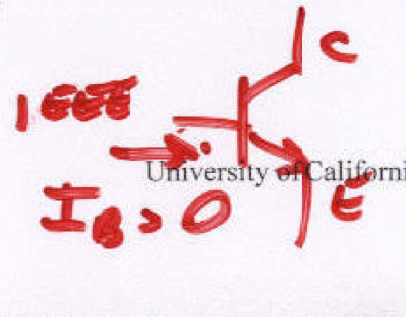
$$J_p^{diff} = -qD_{p_E} \frac{dp_{nB}}{dx} = -qD_{pE} \left\{ \frac{p_{nB}(-x_{BE}) - p_{nB}(-x_{BE} - W_E)}{W_E} \right\}$$

$$= \left(\frac{q D_{pE}}{W_E} \right) p_{nB0} \left[e^{V_{BE}/V_{th}} - 1 \right]$$

$$I_B = \left(\frac{q D_{pE}}{W_E} \right) A_E \, p_{nB0} \left[e^{V_{BE}/V_{th}} - 1 \right]$$

β_F





Current Gain β_F

$$\beta_F = \frac{I_C}{I_B} = \frac{\left(\frac{qD_n n_{pBo} A_E}{W_B}\right)}{\left(\frac{qD_p p_{nEo} A_E}{W_E}\right)} = \frac{D_{nB}\, n_{pBo} \cdot W_E}{D_{pE}\, p_{nEo} \cdot W_B}$$

Parameter sensitivities:

$n_{pBo} = \frac{n_i^2}{N_{aB}}$

$p_{nEo} = \frac{n_i^2}{N_{dE}}$

$$= \frac{D_{nB}\, n_i^2\, W_E N_{dE}}{D_{pE} N_{aB}\, n_i^2\, W_B}$$

$$\beta_F = \frac{D_{nB}}{D_{pE}} \cdot \frac{W_E N_{dE}}{W_B N_{aB}}$$

$W_E \uparrow$, n^+, p^-, $W_B \downarrow$, 3

Ebers-Moll Equations

Exp. 6: measure E-M parameters

Derivation: write emitter and collector currents in terms of internal currents at two junctions

DIODE EB   BC DIODE.

$$I_E = -I_{ES}\left(e^{V_{BE}/V_{th}} - 1\right) + \alpha_R I_{CS}\left(e^{V_{BC}/V_{th}} - 1\right)$$

$$I_C = \alpha_F I_{ES}\left(e^{V_{BE}/V_{th}} - 1\right) - I_{CS}\left(e^{V_{BC}/V_{th}} - 1\right)$$

$$\alpha_F I_{ES} = \alpha_R I_{CS}$$

← "RECIPROCITY"