Chapter 10.

BJT Fundamentals

Sung June Kim

kimsj@snu.ac.kr

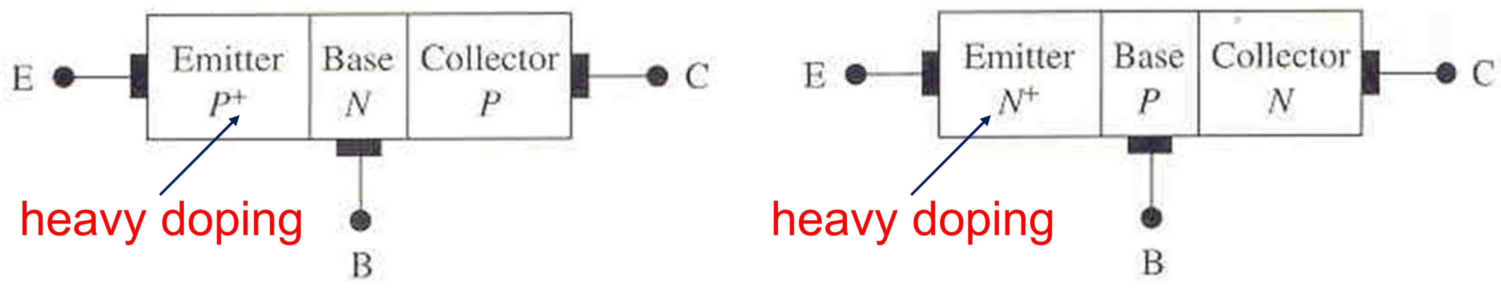
http://helios.snu.ac.kr

Contents

- Drift
- Diffusion
- Generation-Recombination
- Equations of State

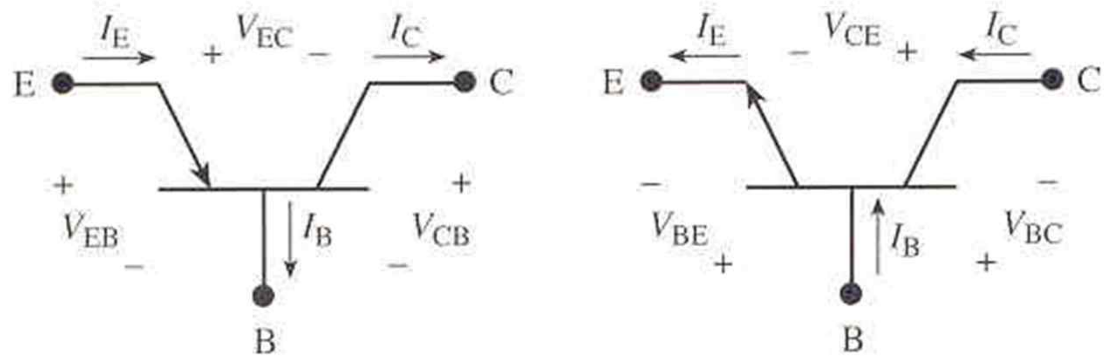
❑ Terminology

✓ The BJT is a device containing three adjoining, alternately doped regions, with the middle region being very narrow compared to the diffusion length



(a) *pnp* (b) *npn*

✓ All terminal currents are positive when the transistor is operated in the standard amplifying mode



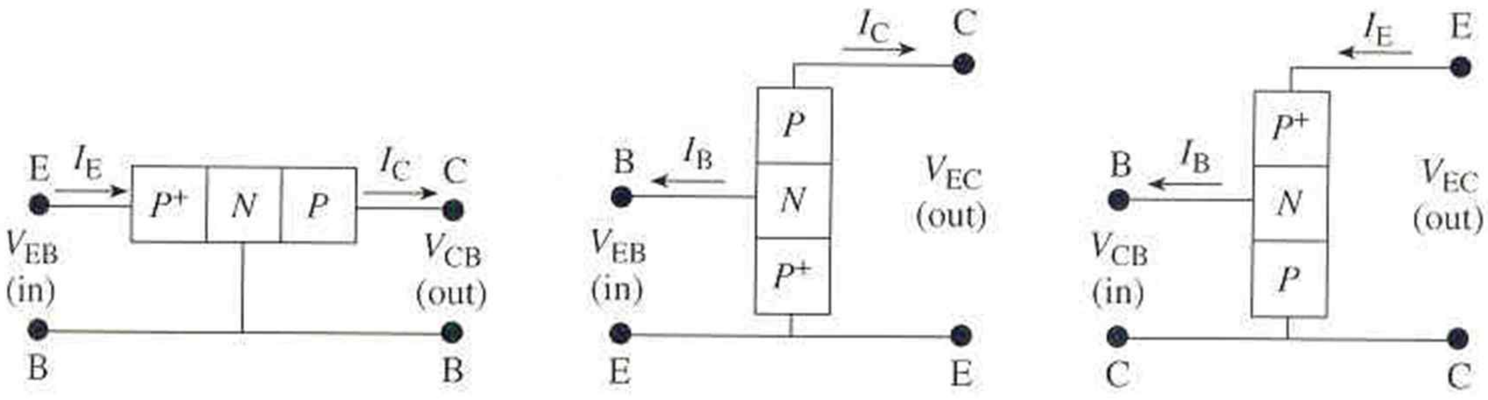
(a) *pnp* (b) *npn*

✓ The current flowing into a device must be equal to the current flowing out, and voltage drop around a closed loop must be equal to zero

$$I_E = I_B + I_C$$

$$V_{EB} + V_{BC} + V_{CE} = 0 \quad (V_{CE} = -V_{EC})$$

✓ The basic *circuit configuration* in which the device is connected and the *biasing mode*



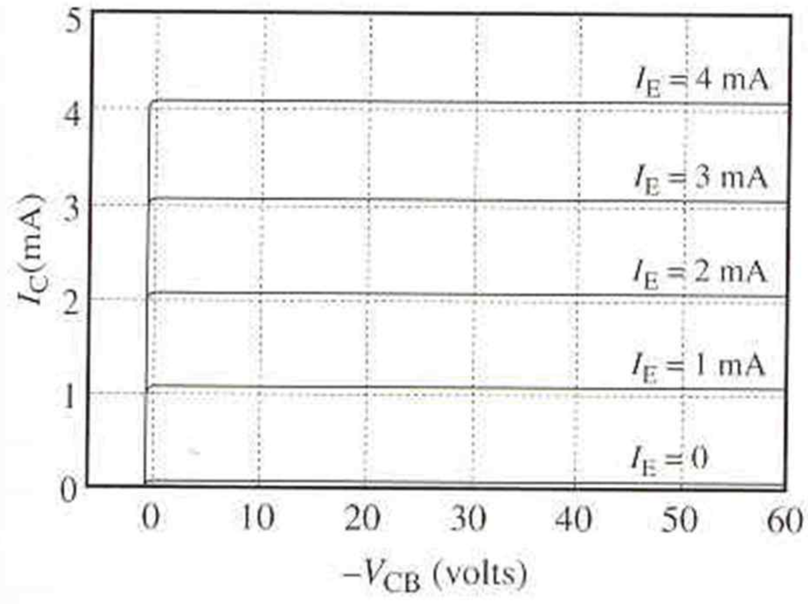
(a) Common base

(b) Common emitter

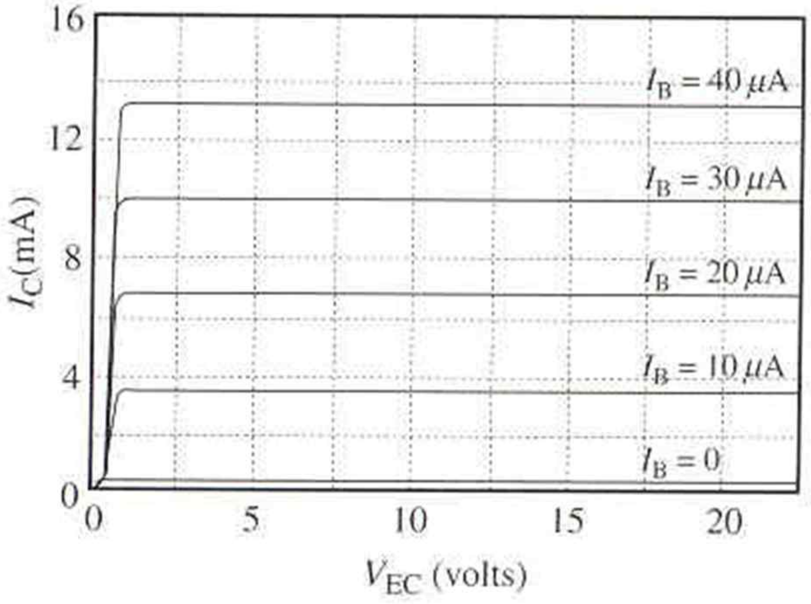
(c) Common collector

The most widely employed configuration

Seldom used



(a) Common base

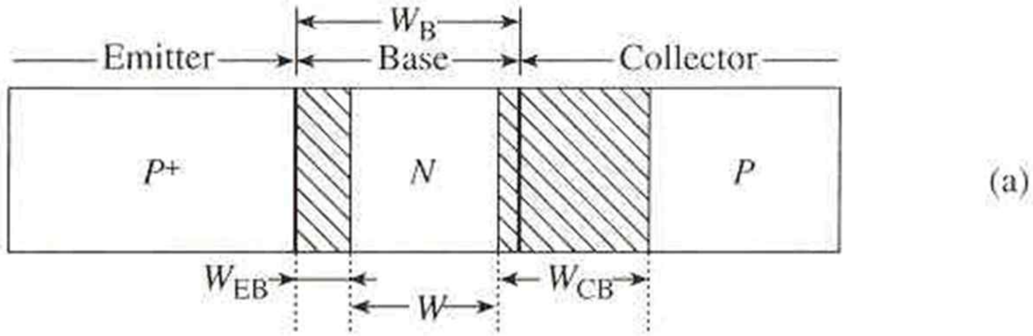


(b) Common emitter

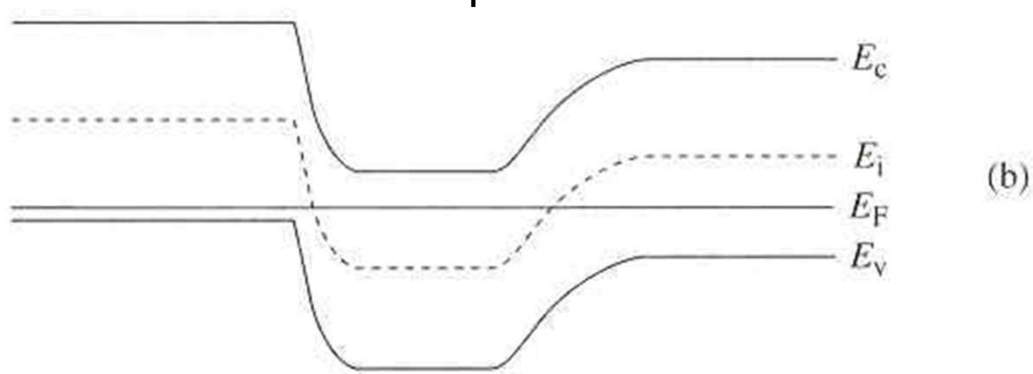
Biasing Mode	*Biasing Polarity E-B Junction*	*Biasing Polarity C-B Junction*
Saturation	Forward	Forward
Active	**Forward**	**Reverse**
Inverted	Reverse	Forward
Cutoff	Reverse	Reverse

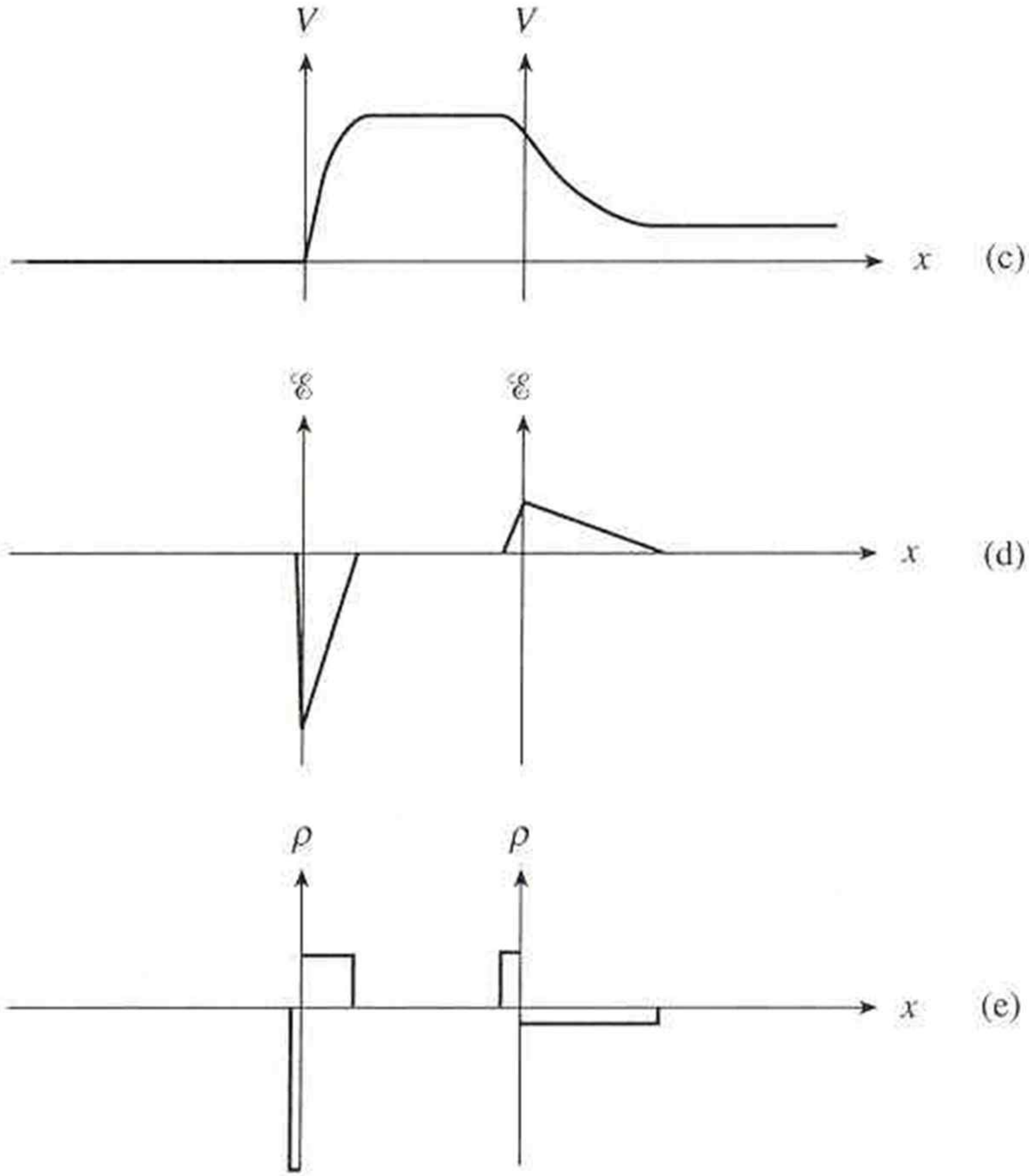
✓ Although the *npn* BJT is used in a far greater number of circuit applications and IC designs, the *pnp* BJT is a more convenient vehicle for establishing operational principles and concepts

- Electrostatics
  - ✓Two independent pn junctions
  - ✓Assuming the *pnp* transistor regions to be uniformly doped and taking N_{AE} (E) >> N_{DB} (B) > N_{AC} (C)

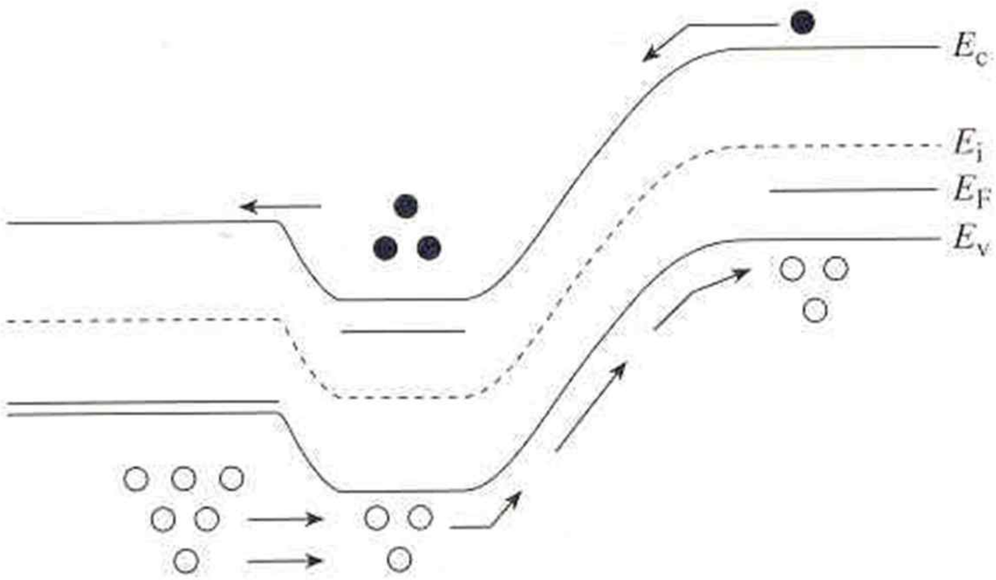


W=quasineutral base width




V
V
x
(c)
ℰ
ℰ
x
(d)
ρ
ρ
x
(e)

❑ Introductory Operational Considerations



Carrier activity in a *pnp* BJT under active mode biasing

✓ The primary carrier activity in the vicinity of the forward-biased E-B junction is majority carrier injection across the junction

✓The p^+-n nature of the junction leads to many more holes being injected than electrons being injected

✓ The vast majority of holes diffuse completely through the quasineutral base and enter the C-B depletion region

✓The accelerating electric field in the C-B depletion region rapidly sweeps these carriers into the collector

✓ I_{Ep}: the hole current injected into the base, I_{En}: the electron current injected into the emitter, I_{Cp}: a current almost exclusively resulting from the injected holes that successfully cross the base, I_{Cn}: a current from the minority carrier electrons in the collector that wander into the C-B depletion region and are swept into the base

✓ Very few of the injected holes are lost by recombination in the base → $I_{Cp} \approx I_{Ep}$

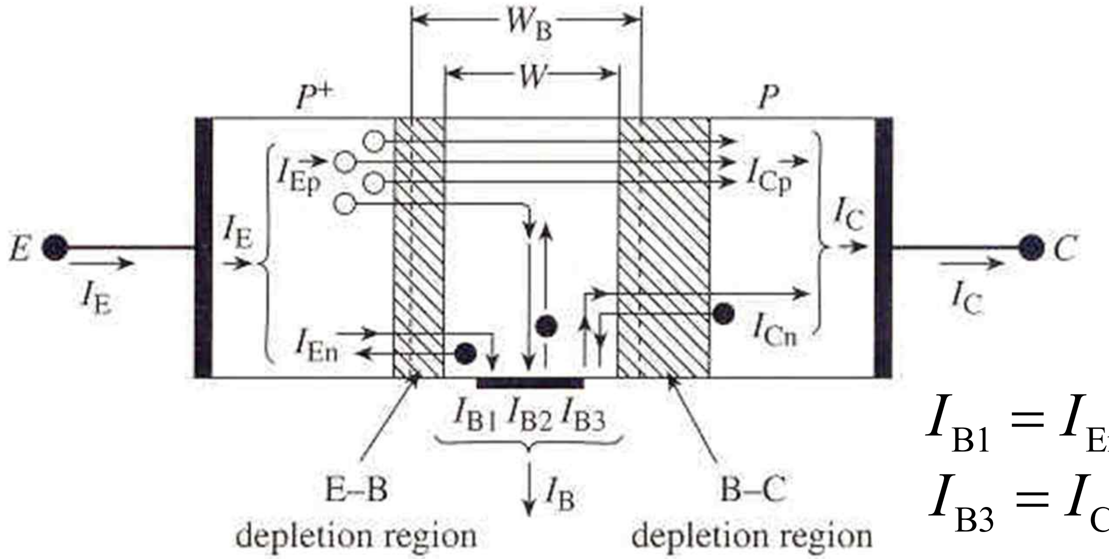
$$I_E = I_{Ep} + I_{En}$$

$$I_C = I_{Cp} + I_{Cn}$$

$$I_{E_P} >> I_{En}$$

$$I_{C_P} >> I_{Cn}$$

$$\therefore I_C \cong I_E$$

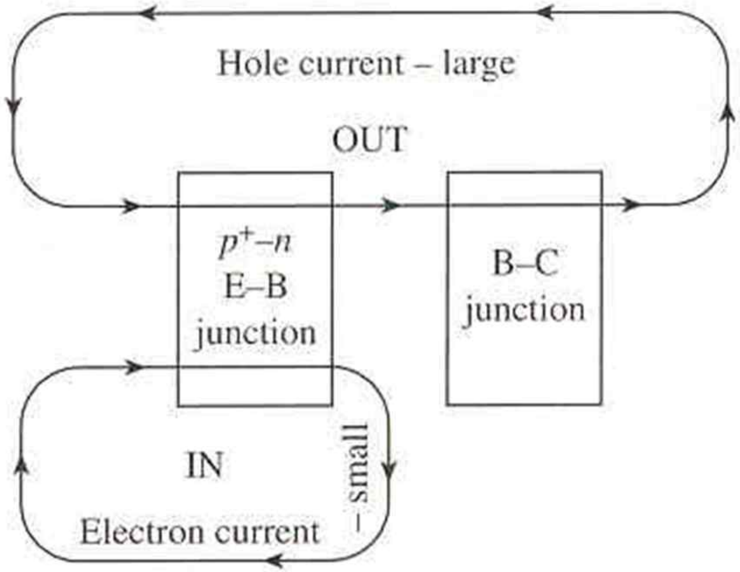


$$I_{B1} = I_{En}$$

$$I_{B3} = I_{Cn}$$

$$I_{B2} = \text{recombination current in B}$$

✓ d.c. current gain: I_C/I_B, where I_B is an electron current in a *pnp* BJT and I_C is predominantly a hole current



Schematic visualization of amplification in a *pnp* BJT under active mode biasing

✓ Control of the larger I_C by the smaller I_B is made possible

❑ Performance Parameters

• Emitter Efficiency

$$\gamma = \frac{I_{E_P}}{I_E} = \frac{I_{E_P}}{I_{E_P} + I_{E_n}} \qquad 0 \le \gamma \le 1$$

✓ Current gain is maximized by making γ as close as possible to unity

• Base Transport Factor

✓ The fraction of the minority carriers injected into the base that successfully diffuse across the quasineutral width of the base and enter the collector

$$\alpha_T = \frac{I_{C_p}}{I_{E_p}} \qquad 0 \le \alpha_T \le 1$$

✓ Maximum amplification occurs when α_T is as close as possible to unity

- Common Base d.c. Current Gain
  - ✓ When connected in the common base configuration,

$$I_C = \alpha_{dc} I_E + I_{CB0}$$

where is α_{dc} the common base d.c. current gain and I_{CB0} is the collector current that flows when I_E=0

$$I_{Cp} = \alpha_T I_{Ep} = \gamma \alpha_T I_E$$

$$I_C = I_{Cp} + I_{Cn} = \gamma \alpha_T I_E + I_{Cn}$$

$$\boxed{\alpha_{dc} = \gamma \alpha_T} \qquad 0 \le \alpha_{dc} \le 1$$

$$I_{CBO} = I_{Cn}$$

- Common Emitter d.c. Current Gain
  - ✓ When connected in the common emitter configuration,

$$I_C = \beta_{dc} I_B + I_{CE0}$$

where is β_{dc} the common emitter d.c. current gain and I_{CE0} is the collector current that flows when I_B=0

$$I_C = \alpha_{dc}(I_C + I_E) + I_{CE0}$$

$$\because I_C = \alpha_{dc} I_E + I_{CB0},$$
$$I_E = I_C + I_B$$

✓ Rearranging and solving for I_C,

$$I_C = \frac{\alpha_{dc}}{1-\alpha_{dc}} I_B + \frac{I_{CB0}}{1-\alpha_{dc}}$$

$$\boxed{\beta_{\mathrm{dc}} = \frac{\alpha_{\mathrm{dc}}}{1-\alpha_{\mathrm{dc}}}} \quad \beta_{dc} >> 1$$

$$I_{CE0} = \frac{I_{CB0}}{1-\alpha_{dc}}$$

$$\beta_{\mathrm{dc}} = \frac{I_{\mathrm{C}}}{I_{\mathrm{B}}}$$

If I_{CE0} is negligible compared to I_C

Summary

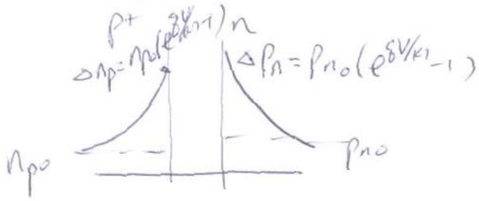
Summary

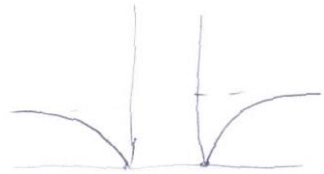
Ch 10 BJT 11/09/10

Minority carrier conc

fwd bias

Rev. Bias

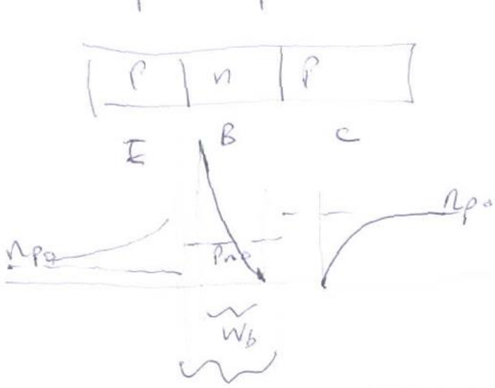




$\Delta n_p = -n_{p0}$ $\Delta p_n = p_{n0}(e^{qV/kT}-1)$
$= -p_{n0}$

BJT $p^+ \; n \; p^-$

Active Mode Bias
fwd & Rev.



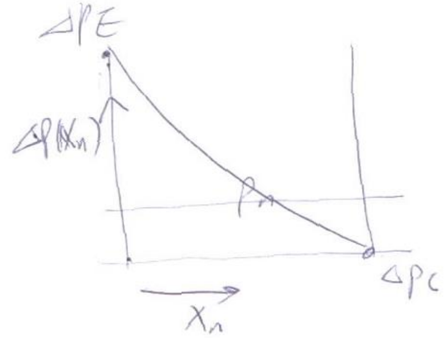
ok

⇓

~ narrow base diode

if $\Delta p_n \cong 0$

$\Delta p_n(x) = p_{n0} \dfrac{\sinh\left((W_b - x)/L_p\right)}{\sinh(x/L_p)}$



$$\Delta p_E = p_n(e^{qV_{EB}/kT} - 1) \doteq p_n e^{qV_{EB}/kT}$$

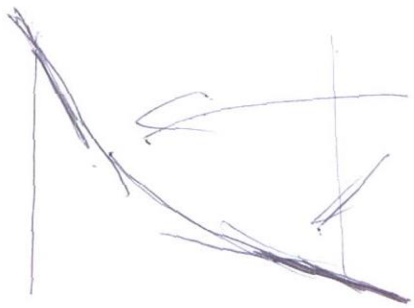
$$\Delta p_C = p_n(e^{qV_{CB}/kT} - 1) \doteq -p_n$$

diffusion eq. $\dfrac{d^2 \Delta p(x_n)}{dx_n^2} = -\dfrac{\Delta p(x_n)}{L_p^2}$ $\left(\leftarrow D \dfrac{d^2 \Delta p}{dx^2} = -\dfrac{\Delta p}{\tau} \right)$

sol. $\Delta p(x_n) = C_1 e^{\frac{x}{L_p}} + C_2 e^{-x_n/L_p}$

if $\Delta p_C \simeq 0$

$$\Delta p(x_n) = \Delta p_E \cdot \frac{e^{W_b/L_p} e^{-x_n/L_p} - e^{-W_b/L_p} e^{x_n/L_p}}{e^{W_b/L_p} - e^{W_b/L_p}}$$



Difference in these two slopes difference $|I_E - I_C| = |I_B|$

diff. current $I_p(x_n) = -qAD_p \dfrac{d \Delta p(x_n)}{dx_n}$

$\rightarrow I_{Ep} = I_p \big|_{x_n=0} = qA\dfrac{D_p}{L_p}(C_2 - C_1) = \cdots$

$\simeq I_E$ (Emitter Injection Efficiency $\gamma = 1$) reasonable.

$I_{Cp} = I_p \big|_{x_n = W_b} = qA\dfrac{D_p}{L_p}(C_2 e^{-W_n/L_p} - C_1 e^{W_b/L_p})$

$\simeq I_C$ (ignoring ~~saturation~~ Rev. bias sat. current

~~Equations~~

More Exact Analysis (considering both ΔP_E, ΔP_C)

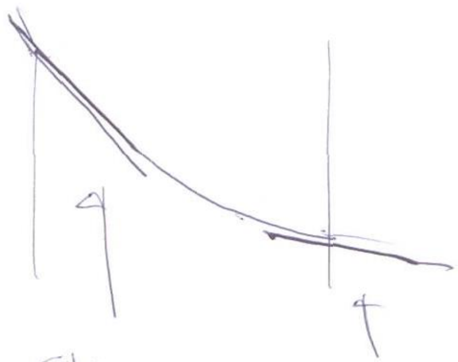
Then $I_E - I_C = I_B$

$$I_{Ep} = qA \frac{D_p}{L_p}\left(\Delta P_E \operatorname{ctnh}\frac{W_b}{L_p} - \Delta P_C \operatorname{csch}\frac{W_b}{L_p}\right)$$

$$I_C = qA \frac{D_p}{L_p}\left(\Delta P_E \operatorname{csch}\frac{W_b}{L_p} - \Delta P_C \operatorname{ctnh}\frac{W_b}{L_p}\right)$$

$$\rightarrow I_B = qA \frac{D_p}{L_p}\left[\Delta P_E + \Delta P_C\right) \tanh\frac{W_b}{2L_p}.$$

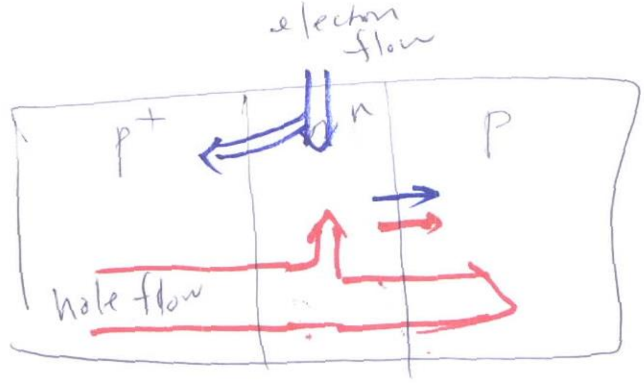
$p(x)$



This slope determines I_E

This slope determines I_C

The difference is the I_B.

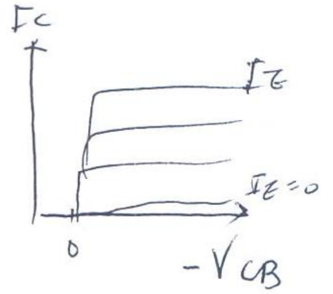


Now Go to the ~~Front~~ &
explain the whole thing!

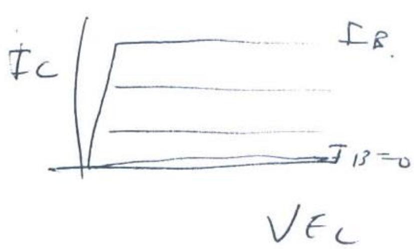
ch 10.

11/11/10.

I_{CBO}



I_{CEO}



$I_{CBO} = \underbrace{I_{Cn}}$.
↓
Sat current.
OR a leakage current term
that includes ~~other~~
generation current.

$I_{CEO} = \dfrac{I_{CBO}}{1-\alpha_{dc}}$