CHAPTER 10

10.1

(a) Common base.

(b) Common emitter.

(c) Saturation, active, inverted, and cutoff.

(d) The buried layer serves as a low-resistance path between the active collector region of the BJT and the top-side collector contact.

(e) $N_{AE} >> N_{DB} > N_{AC}$

(f) W in both cases.

(g) The width of the base is less than, typically much less than, the minority carrier diffusion length in the base.

(h) The narrow nature of the base couples the current flow across the E-B and C-B junctions, a prerequisite for transistor action.

(i) The emitter efficiency specifies the fraction of the emitter current that is associated with carrier injection from the emitter into the base.

(j) The base transport factor is the fraction of the minority carriers injected into the base that successfully diffuse across the quasineutral width of the base and enter the collector.

10.2

(a) *pnp*

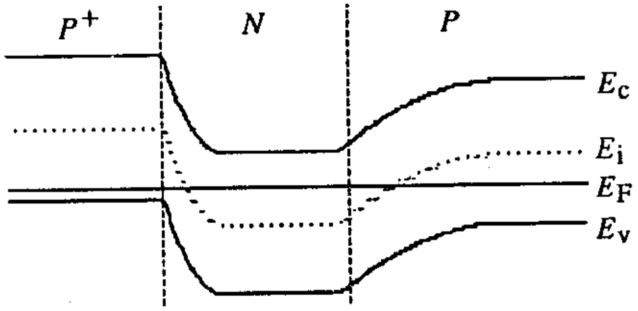
Mode	V_{EB}	V_{CB}
Active	+	−
Inverted	−	+
Saturation	+	+
Cutoff	−	−

(b) *npn*

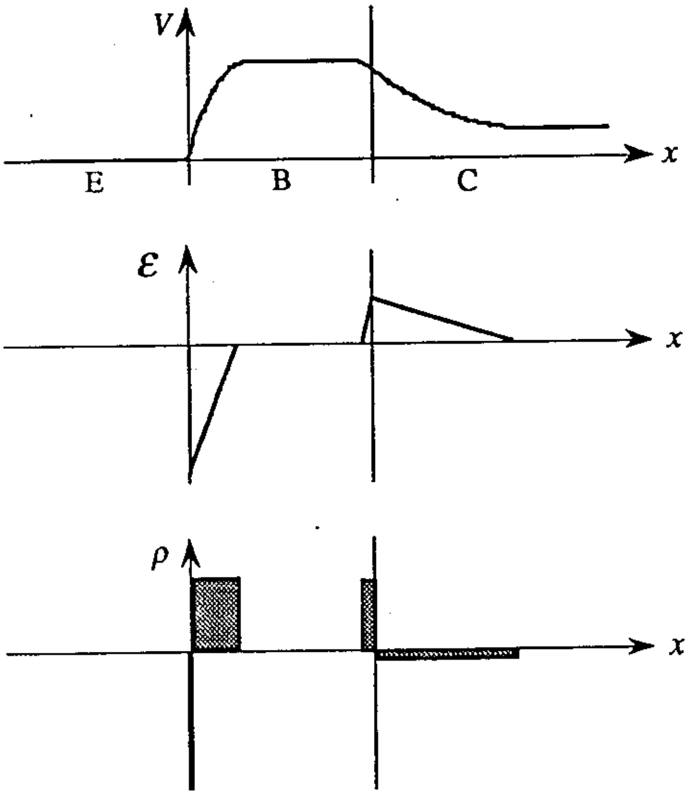
Mode	V_{BE}	V_{BC}
Active	+	−
Inverted	−	+
Saturation	+	+
Cutoff	−	−

10.3

(a) For the given doping concentrations, one computes $E_F - E_i = -0.459\text{eV}$, 0.298eV, and -0.239eV respectively in the emitter, base, and collector. Also, with $N_{AE} >> N_{DB}$, the E-B depletion width will lie almost exclusively in the base. Likewise, the majority of the C-B depletion width will lie in the collector. The diagram produced by the BJT_Eband program is displayed below.



(b)



(c) $\Delta V_{CE} = (1/q)[(E_i - E_F)_{emitter} - (E_i - E_F)_{collector}]$

$$= (kT/q)[\ln(N_{AE}/n_i) - \ln(N_{AC}/n_i)]$$

or

$$\Delta V_{CE} = (kT/q)\ln(N_{AE}/N_{AC}) = (0.0259)\ln(5\times10^{17}/10^{14}) = \mathbf{0.221\ V}$$

(d) As noted in the text (Eq. 10.3),

$$W = W_B - x_{nEB} - x_{nCB}$$

$$x_{nEB} \cong \left[\frac{2K_S\varepsilon_0}{qN_{DB}} V_{biEB}\right]^{1/2} = \left[\frac{(2)(11.8)(8.85\times10^{-14})(0.757)}{(1.6\times10^{-19})(10^{15})}\right]^{1/2} = 9.94\times10^{-5}\ \text{cm}$$

$$x_{nCB} = \left[\frac{2K_S\varepsilon_0}{qN_{DB}}\frac{N_{AC}}{N_{AC}+N_{DB}} V_{biCB}\right]^{1/2} = \left[\frac{(2)(11.8)(8.85\times10^{-14})(10^{14})(0.537)}{(1.6\times10^{-19})(10^{15})(1.1\times10^{15})}\right]^{1/2}$$

$$= 2.52\times10^{-5}\ \text{cm}$$

and therefore

$$W = 3\times10^{-4} - 9.94\times10^{-5} - 2.52\times10^{-5} = 1.75\times10^{-4}\ \text{cm} = \mathbf{1.75\ \mu m}$$

The emitter-base and collector-base built-in voltages (V_{biEB} and V_{biCB}) were deduced from the $E_F - E_i$ values computed in part (a).

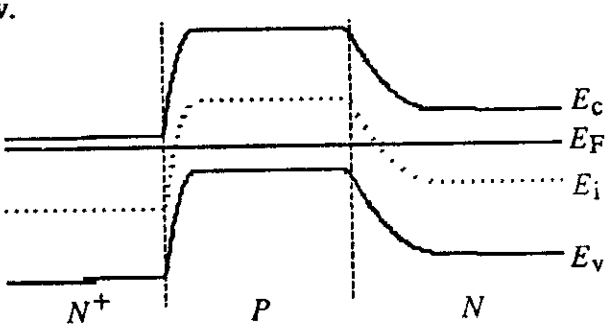
(e)

$$|\mathcal{E}|_{max}(\text{E-B}) = \frac{qN_{DB}}{K_S\varepsilon_0}x_{nEB} = \frac{(1.6\times10^{-19})(10^{15})(9.94\times10^{-5})}{(11.8)(8.85\times10^{-14})} = \mathbf{1.52\times10^4\ V/cm}$$

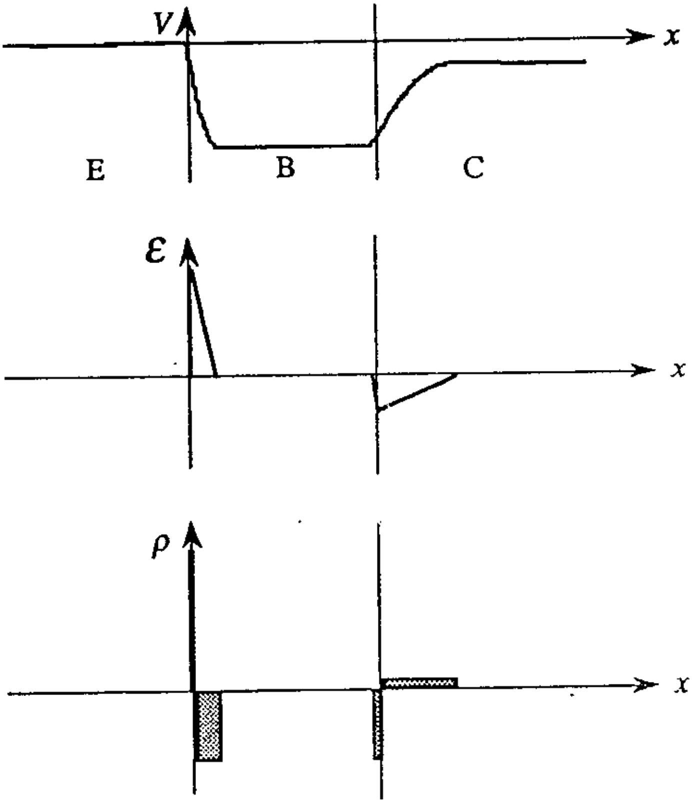
$$\mathcal{E}_{max}(\text{C-B}) = \frac{qN_{DB}}{K_S\varepsilon_0}x_{nCB} = \frac{(1.6\times10^{-19})(10^{15})(2.52\times10^{-5})}{(11.8)(8.85\times10^{-14})} = \mathbf{3.86\times10^3\ V/cm}$$

10.4

(a) For the given doping concentrations, one computes $E_F - E_i = 0.477\text{eV}$, -0.358eV, and 0.298eV respectively in the emitter, base, and collector. Also, with $N_{DE} >> N_{AB}$, the E-B depletion width will lie almost exclusively in the base. Likewise, the majority of the C-B depletion width will lie in the collector. The diagram produced by the BJT_Eband program is displayed below.



(b)



(c) $$\Delta V_{CE} = (1/q)[(E_F - E_i)_{collector} - (E_F - E_i)_{emitter}]$$
$$= (kT/q)[\ln(N_{DC}/n_i) - \ln(N_{DE}/n_i)]$$

or

$$\Delta V_{CE} = (kT/q)\ln(N_{DC}/N_{DE}) = (0.0259)\ln(10^{15}/10^{18}) = \mathbf{-0.179\ V}$$

(d) Analogous to Eq.(10.3) in the text,

$$W = W_B - x_{pEB} - x_{pCB}$$

$$x_{pEB} \cong \left[\frac{2K_S\varepsilon_0}{qN_{AB}} V_{biEB}\right]^{1/2} = \left[\frac{(2)(11.8)(8.85\times10^{-14})(0.835)}{(1.6\times10^{-19})(10^{16})}\right]^{1/2} = 3.30\times10^{-5}\ \text{cm}$$

$$x_{pCB} = \left[\frac{2K_S\varepsilon_0}{qN_{AB}} \frac{N_{DC}}{N_{DC}+N_{AB}} V_{biCB}\right]^{1/2} = \left[\frac{(2)(11.8)(8.85\times10^{-14})(10^{15})(0.656)}{(1.6\times10^{-19})(10^{16})(1.1\times10^{16})}\right]^{1/2}$$

$$= 8.82\times10^{-6}\ \text{cm}$$

and therefore

$$W = 2\times10^{-4} - 3.30\times10^{-5} - 8.82\times10^{-6} = 1.58\times10^{-4}\ \text{cm} = \mathbf{1.58\ \mu m}$$

The emitter-base and collector-base built-in voltages (V_{biEB} and V_{biCB}) were deduced fron the $E_F - E_i$ values computed in part (a).

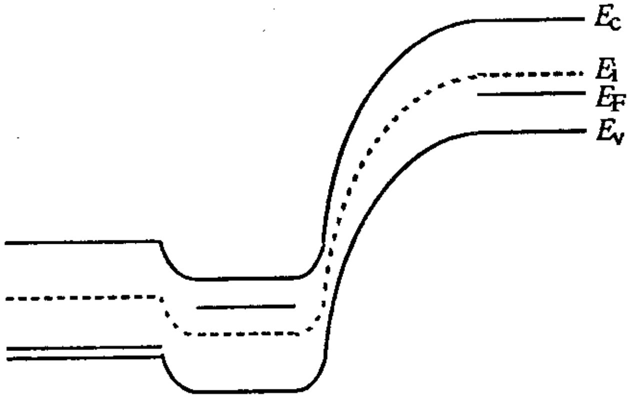
(e)

$$\mathcal{E}_{max}(\text{E-B}) = \frac{qN_{AB}}{K_S\varepsilon_0} x_{pEB} = \frac{(1.6\times10^{-19})(10^{16})(3.30\times10^{-5})}{(11.8)(8.85\times10^{-14})} = \mathbf{5.06\times10^4\ V/cm}$$

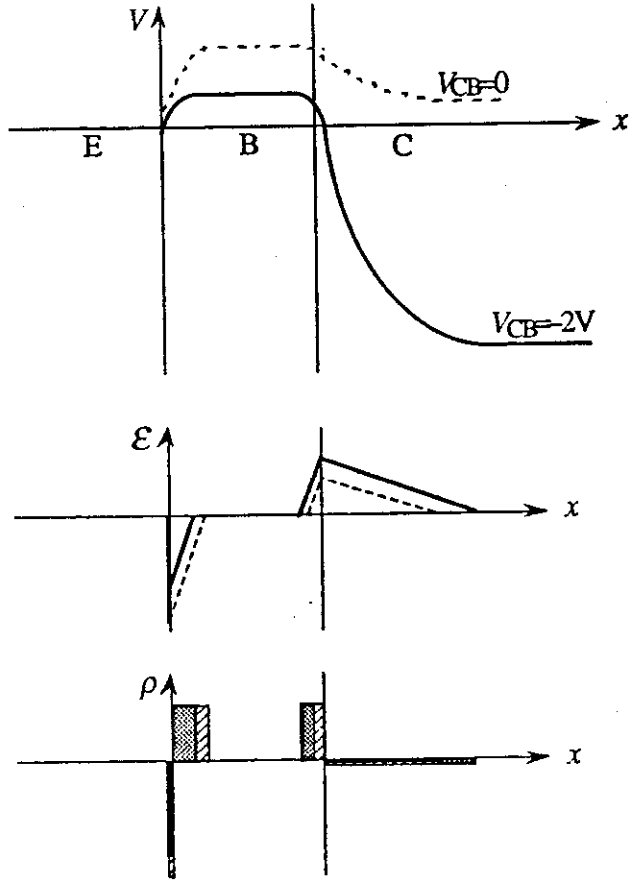
$$|\mathcal{E}|_{max}(\text{C-B}) = \frac{qN_{AB}}{K_S\varepsilon_0} x_{pCB} = \frac{(1.6\times10^{-19})(10^{16})(8.82\times10^{-6})}{(11.8)(8.85\times10^{-14})} = \mathbf{1.35\times10^4\ V/cm}$$

10.5

(a)

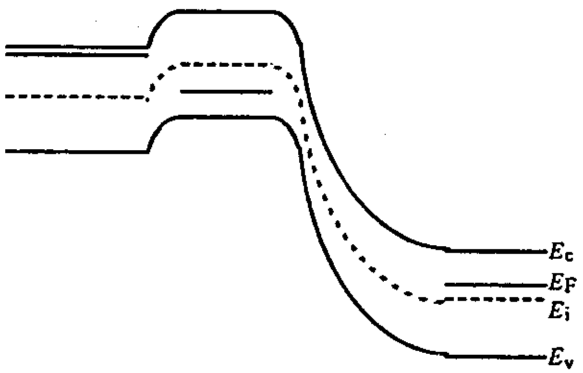


(b)

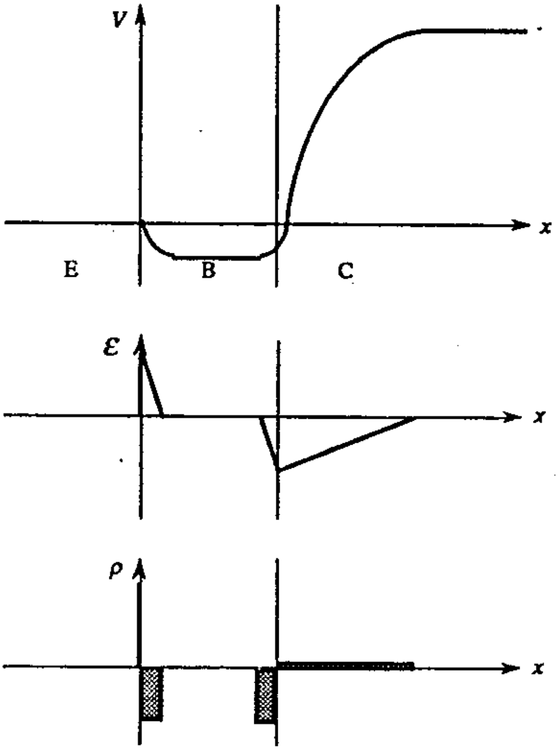


10.6

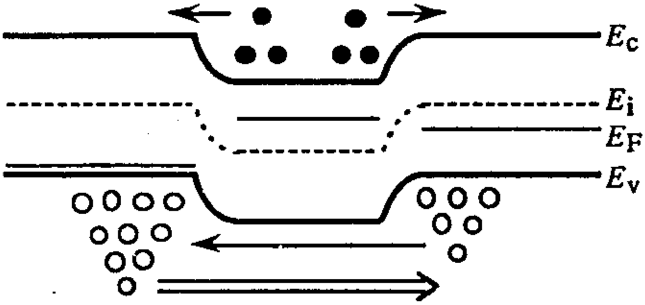
The energy band diagram for a typically doped Si *npn* transistor under equilibrium conditions was sketched in Fig. E10.1(a). Under active mode biasing in the *npn* transistor $V_{BE} > 0$ and $V_{BC} < 0$. Appropriately modifying the Fig. E10.1(a) diagram to account for the applied biases, we conclude



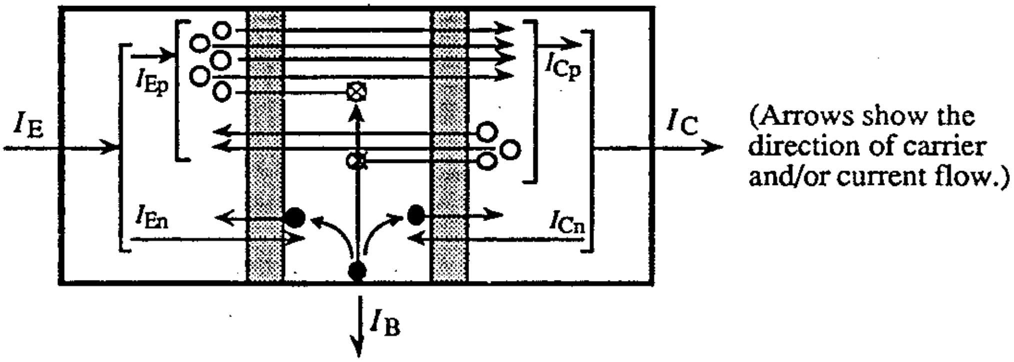
Following the usual procedures in interpreting the energy band diagram to deduce the electrostatic variables, we conclude



10.7

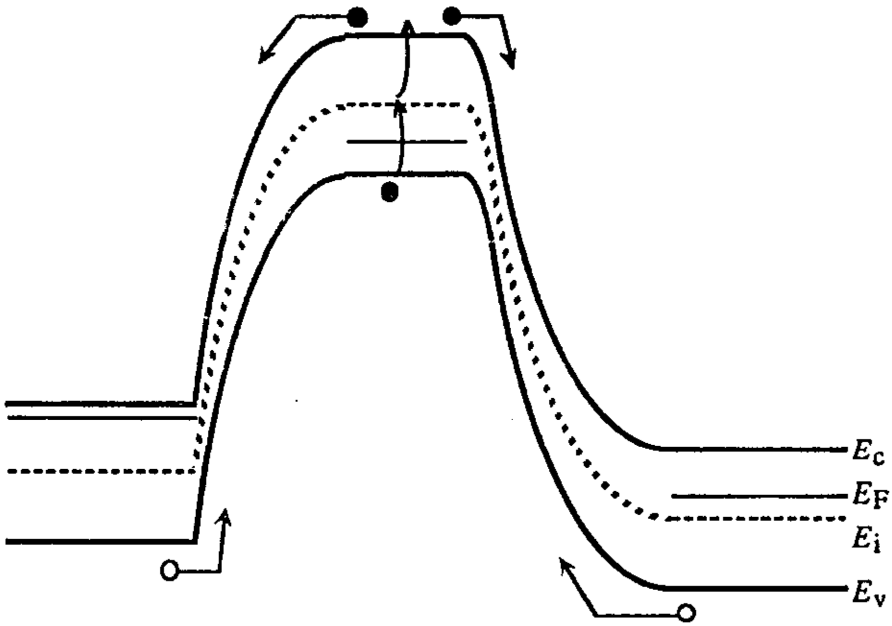


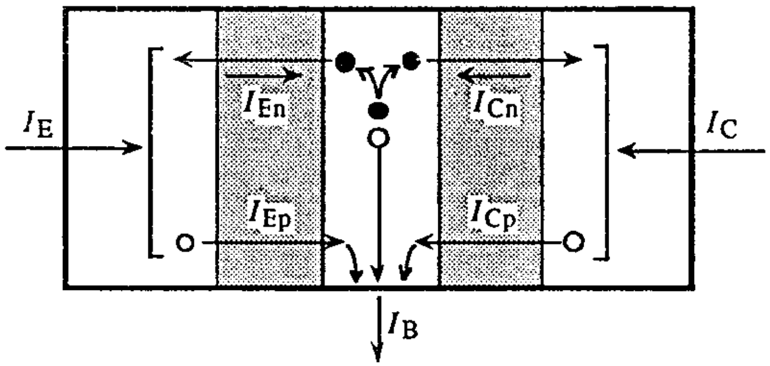
E_c
E_i
E_F
E_v



I_E
I_{Ep}
I_{En}
I_{Cp}
I_{Cn}
I_C
I_B
(Arrows show the direction of carrier and/or current flow.)

10.8





10.9

(a) $$\alpha_T = \frac{I_{CP}}{I_{EP}} = \frac{0.98\text{ mA}}{1\text{ mA}} = \mathbf{0.9800}$$

(b) $$\gamma = \frac{I_{Ep}}{I_{Ep} + I_{En}} = \frac{1\text{mA}}{1\text{mA} + 0.01\text{mA}} = \mathbf{0.9901}$$

(c) $$I_E = I_{Ep} + I_{En} = 1\text{mA} + 0.01\text{mA} = \mathbf{1.01\ mA}$$

$$I_C = I_{Cp} + I_{Cn} = 0.98\text{mA} + 0.1\mu\text{A} = \mathbf{0.9801\ mA}$$

$$I_B = I_E - I_C = 1.01\text{mA} - 0.9801\text{mA} = \mathbf{29.9\ \mu A}$$

(d) $$\alpha_{dc} = \gamma\alpha_T = \mathbf{0.9703}$$

$$\beta_{dc} = \frac{\alpha_{dc}}{1-\alpha_{dc}} = \frac{0.9703}{1-0.9703} = \mathbf{32.7}$$

(e) As given by Eq. (10.12),

$$I_{CB0} = I_{Cn} = \mathbf{0.1\mu A}$$

Likewise, Eq. (10.17) states

$$I_{CE0} = \frac{I_{CB0}}{1-\alpha_{dc}} = \frac{0.1\ \mu\text{A}}{1-0.9703} = \mathbf{3.37\mu A}$$

(f) The I_{Cp} increase while I_{Ep} remains fixed indicates that the base transport factor has been improved. An increase in α_T in turn leads to an increase in $\alpha_{dc} = \gamma\alpha_T$ and therefore to an **increase in β_{dc}**.

(g) An increase in I_{En} while I_{Ep} remains fixed indicates that the emitter efficiency has been degraded. A decrease in γ in turn leads to a decrease in $\alpha_{dc} = \gamma\alpha_T$ and therefore to a **decrease in β_{dc}**.

10.10

(a) $$\alpha_T = \frac{I_{Cn}}{I_{En}} = \frac{99\ \mu A}{100\ \mu A} = \mathbf{0.9900}$$

(b) $$\gamma = \frac{I_{En}}{I_{En} + I_{Ep}} = \frac{100\mu A}{100\mu A + 1\mu A} = \mathbf{0.9901}$$

(c) $$I_E = I_{En} + I_{Ep} = 100\mu A + 1\mu A = \mathbf{101\mu A}$$

$$I_C = I_{Cn} + I_{Cp} = 99\mu A + 0.1\mu A = \mathbf{99.1\mu A}$$

$$I_B = I_E - I_C = 101\mu A - 99.1\mu A = \mathbf{1.9\ \mu A}$$

(d) $$\alpha_{dc} = \gamma\alpha_T = \mathbf{0.9802}$$

$$\beta_{dc} = \frac{\alpha_{dc}}{1-\alpha_{dc}} = \frac{0.9802}{1-0.9802} = \mathbf{49.5}$$

(e) Analogous to Eq. (10.12),

$$I_{CB0} = I_{Cp} = \mathbf{0.1\mu A}$$

Likewise, analogous to Eq. (10.17),

$$I_{CE0} = \frac{I_{CB0}}{1-\alpha_{dc}} = \frac{0.1\ \mu A}{1-0.9802} = \mathbf{5.05\mu A}$$

(f) The I_{Cn} increase while I_{En} remains fixed indicates that the base transport factor has been improved. An increase in α_T in turn leads to an increase in $\alpha_{dc} = \gamma\alpha_T$ and therefore to **an increase in β_{dc}**.

(g) An increase in I_{Ep} while I_{En} remains fixed indicates that the emitter efficiency has been degraded. A decrease in γ in turn leads to a decrease in $\alpha_{dc} = \gamma\alpha_T$ and therefore to a **decrease in β_{dc}**.

10.11

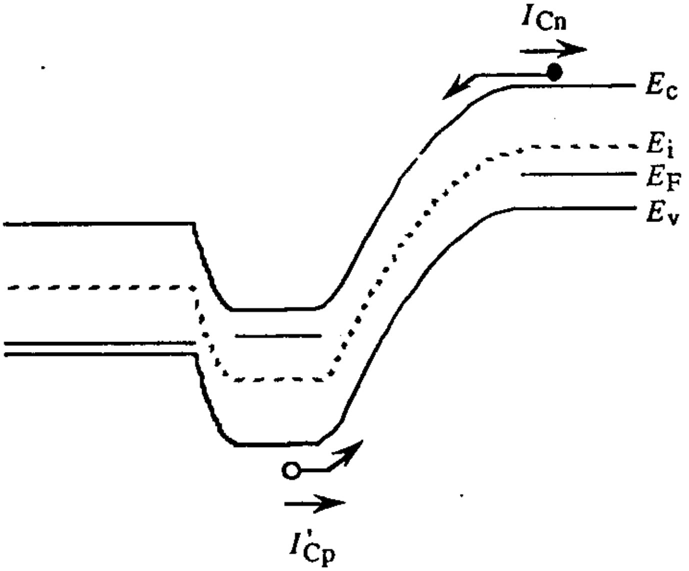
As pictured below, there will indeed be some minority carrier holes in the base that wander into the C-B depletion region and thereby contribute to I_{CB0}. However, because the base is very narrow, the quasineutral region generation that sustains the hole current is expected to be small, and the hole current itself is therefore expected to be negligible compared to I_{Cn}. Quantitatively, employing an analysis similar to that in Exercise 6.4,

$$I_{Cn} = q(AL_C)\left(\frac{n_i^2/N_{AC}}{\tau_C}\right) = qA\frac{n_i^2}{N_{AC}}\frac{D_C}{L_C}$$

and

$$I'_{Cp} < q(AW)\left(\frac{n_i^2/N_{DB}}{\tau_B}\right) = qA\frac{n_i^2}{N_{DB}}\frac{D_B}{L_B}\frac{W}{L_B}$$

where the B and C subscripts refer to parameters in the base and collector, respectively. Since $N_{DB} > N_{AC}$ and $W/L_B << 1$, and assuming $D_C/L_C \sim D_B/L_B$, we again conclude $I_{Cp}' << I_{Cn}$.



$$\ldots I_{CB0} = I_{Cn} + I'_{Cp}$$
$$(I_E = 0)$$