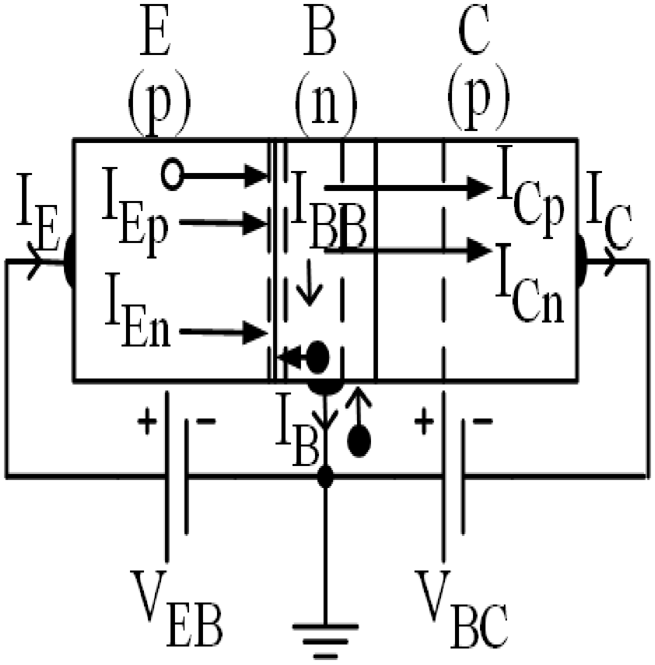
CLASS 3&4

BJT currents, parameters and circuit configurations

- $I_E = I_{Ep} + I_{En}$
- $I_C = I_{Cp} + I_{Cn}$
- $I_B = I_{BB} + I_{En} - I_{Cn}$
- $I_{BB} = I_{Ep} - I_{Cp}$
- $I_E = I_B + I_C$
- I_{En} = current produced by the electrons injected from B to E
- I_{Cn} = current from the electrons thermally generated near the edge of the C-B junction that drifted from C to B.
- $I_B = I_E - I_C$
- $= I_{Ep} + I_{En} - I_{Cp} - I_{Cn}$
- $= I_{Ep} - I_{Cp} + I_{En} - I_{Cn}$
- $= I_{BB} + I_{En} - I_{Cn}$



- **An important BJT parameter is the common-base (CB) current gain, α_o.**

$$\boxed{\alpha_o = I_{Cp} / I_E}$$

$$= I_{Cp} / (I_{Ep} + I_{En})$$

$$= I_{Cp}\, I_{Ep} / [I_{Ep}(I_{Ep} + I_{En})]$$

$$= [I_{Ep} / (I_{Ep} + I_{En})][I_{Cp} / I_{Ep}]$$

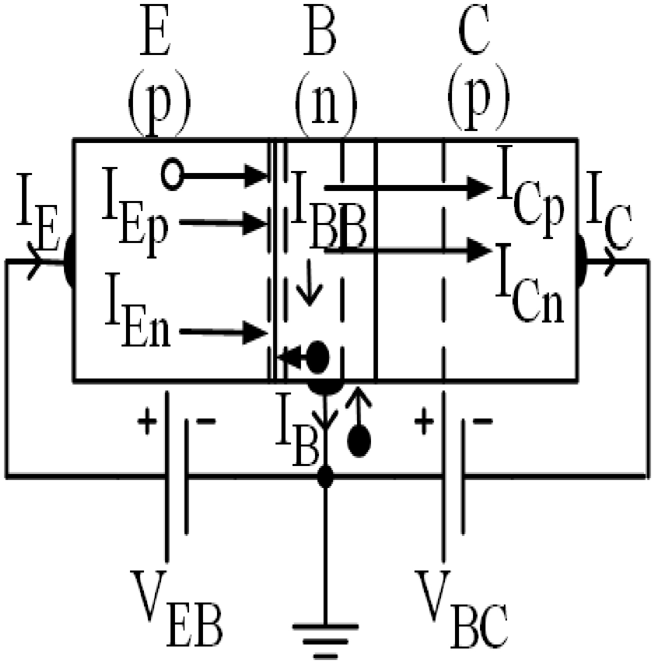
$$\boxed{\alpha_o = \gamma\, \alpha_T}$$

- **Emitter efficiency, $\gamma = I_{Ep} / (I_{Ep} + I_{En})$**

$$\boxed{\gamma = I_{Ep} / I_E}$$

- **Base transport factor,** $\boxed{\alpha_T = I_{Cp} / I_{Ep}}$
- **Since $\alpha_o = \gamma\, \alpha_T$ and $I_{En} << I_{Ep}$, then $I_{Ep} \approx I_E$. Hence, $\gamma \approx 1$.**
- **$I_{Cp} \approx I_{Ep}$. Thus, $\alpha_T \approx 1$. Consequently,**

$$\boxed{\alpha_o \approx 1}$$



- $I_C = I_{Cp} + I_{Cn}$
- As $\alpha_T = I_{Cp} / I_{Ep}$, then $I_C = \alpha_T I_{Ep} + I_{Cn}$
- Since $\alpha_o = \gamma \alpha_T$ and $\gamma = I_{Ep} / I_E$:

  $I_C = (\alpha_o / \gamma) \gamma I_E + I_{Cn}$

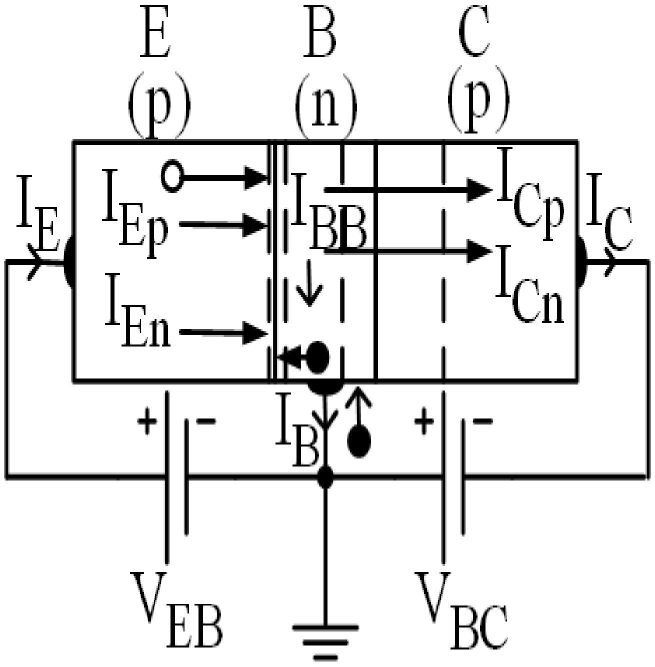
  $I_C = \alpha_o I_E + I_{Cn}$

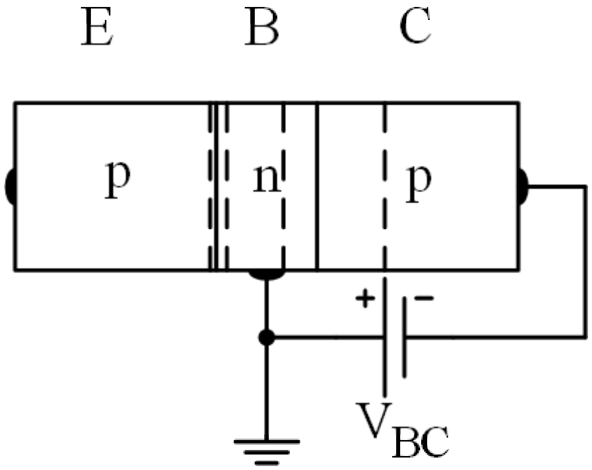
  $\boxed{I_E = I_B + I_C}$

  I_{Cn} can be determined by measuring the current flowing across the B-C junction when E is an open-circuit. $I_E = 0$.

  The value of I_{Cn} under this condition is known as I_{CBO}. I_{CBO} represents the leakage current between C and B when E-B is open circuited.
- Collector current for the CB configuration is represented by the expression:

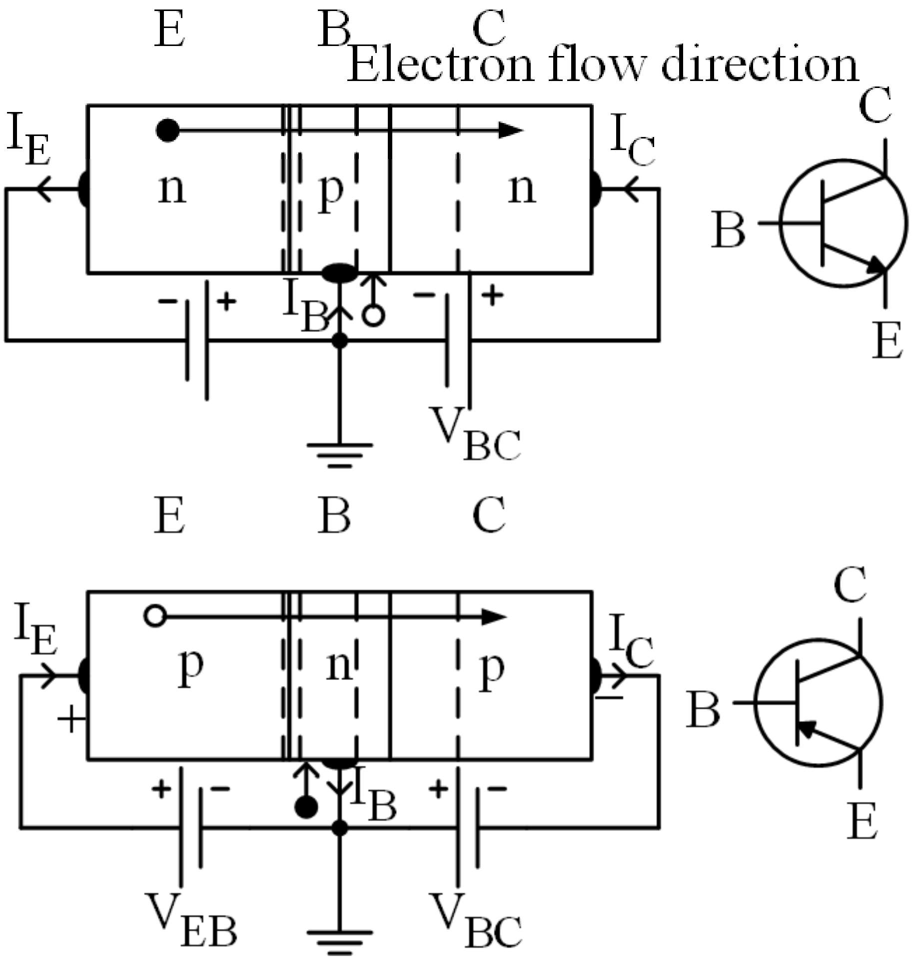
  $\boxed{I_C = \alpha_o I_E + I_{CBO}}$





- **The conventional current flow is always in the opposite direction as the flow of electron.**
- **The conventional current flow is always in the same direction as the flow of holes.**
- **The flow of holes is always opposite with the flow of electrons.**
- **The general equation that relates the emitter, collector and base currents is:**

  $I_E = I_B + I_C$



Holes are injected from E to B when the E-B junction is fb. Holes will then diffuse across B and reach the B-C junction.

$$P_n(0) = p_{no} e^{(qV_{EB})/kT}$$

where:

p_{no} = density of the minority carriers under equilibrium condition.

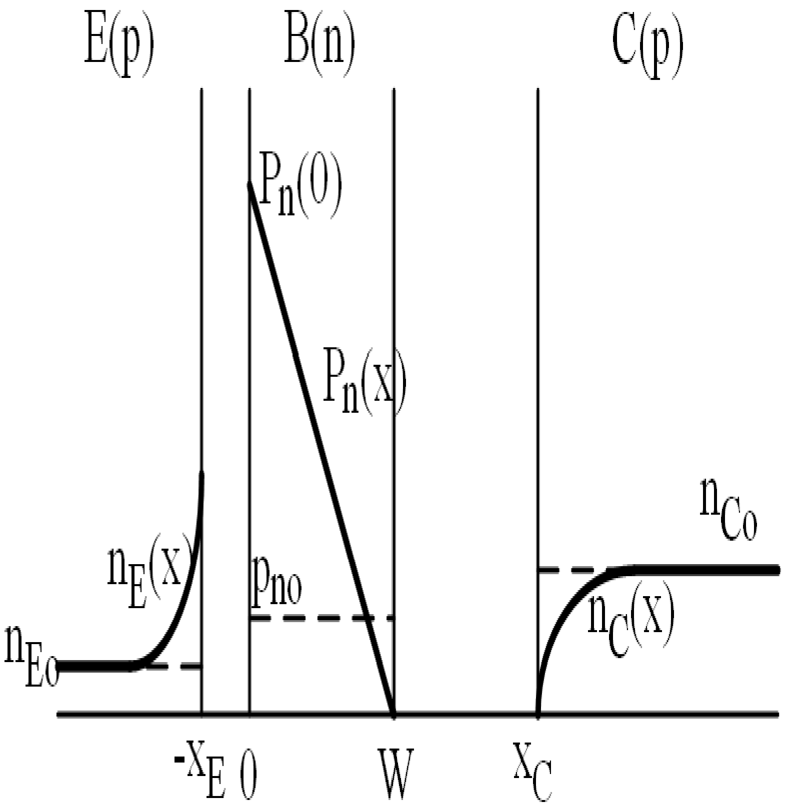
$= n_i^2/N_B$

N_B = donor density in B.

kT/q = temperature equivalent voltage

The existence of the density gradient of holes in B shows that the holes injected from E will diffuse across B to the edge of the B-C depletion region before they are swept into C by the electric field across B-C.

Distribution of the minority carriers in an active mode pnp transistor



$$P_n(0) = p_{no} e^{(qV_{EB})/kT}$$

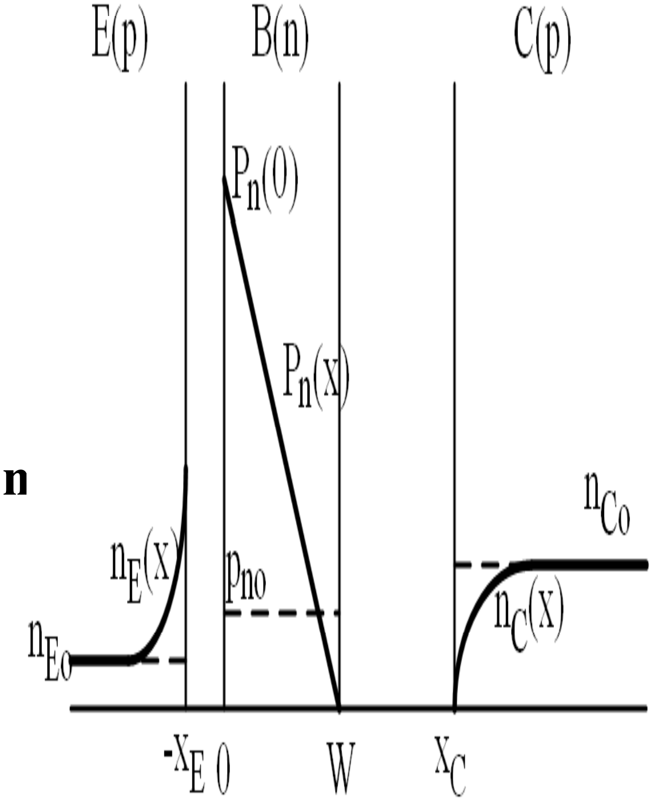
- **If the E-B junction is fb, the minority carrier density at the edge of the E-B depletion region (at x=0) is increased beyond its equilibrium value by a factor of :**

$$e^{(qV_{EB})/kT}$$

- **$P_n(W) = 0$**
- **Under the rb condition, the minority carrier density at the edge of the B-C depletion region (x = W) is 0.**
- **If the B is very narrow (i.e. $W/L_p << 1$):**

$$P_n(x) = p_{no} e^{(qV_{EB})/kT} \left[1-(x/W)\right]$$
$$= P_n(0)\left[1-(x/W)\right]$$

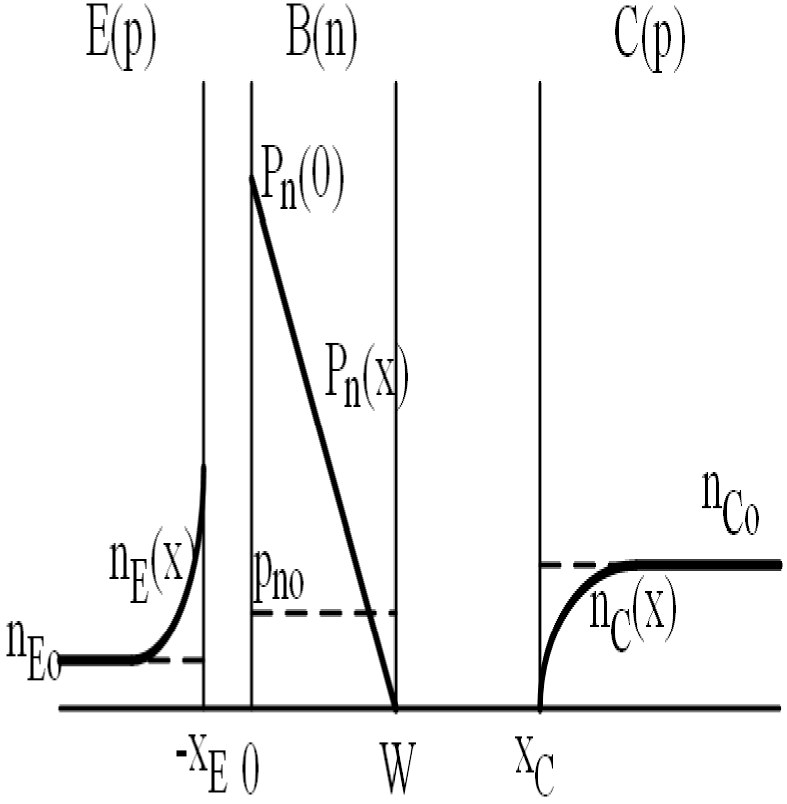
Distribution of the minority carriers in an active mode pnp transistor



$$P_n(x) = p_{no} e^{(qV_{EB})/kT}\left[1-(x/W)\right]$$

This expression is close to the real minority carrier distribution in B. The assumption that the minority carrier distribution in B is linear simplifies the derivation of the I-V characteristic.

Distribution of the minority carriers in an active mode pnp transistor



$$n_E(x=-x_E)=n_{Eo}e^{(qV_{EB})/kT}$$

$$n_C(x=x_C)=n_{Co}e^{-q|V_{CB}|}=0$$

where n_{Eo} and n_{Co} are the electron densities under equilibrium condition for the E and C, respectively.

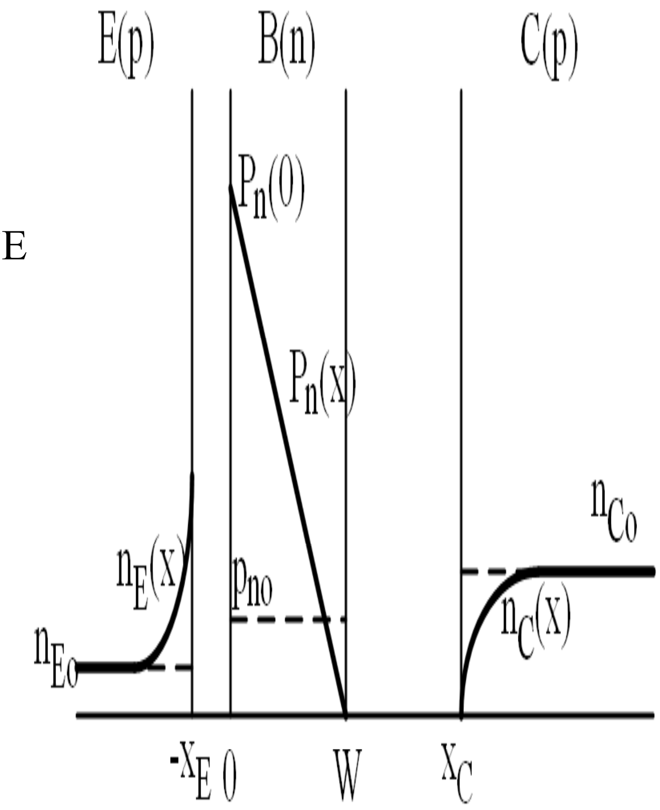
$$n_E(x)=n_{Eo}+n_{Eo}\left[e^{(qV_{EB})/kT}-1\right]e^{(x+x_E)/L_E}$$

for $x \le -x_E$

$$n_C(x)=n_{Co}-n_{Co}e^{-(x-x_C)/L_C}$$

for $x \ge x_C$

Distribution of the minority carriers in an active mode pnp transistor



Transistor currents in the active mode of operation

The hole current, I_{Ep} , injected from E at x=0 is proportional to the gradient of the minority carrier density.

$$I_{Ep} = A\left[-qD_p \frac{dP_n(x)}{dx}\bigg|_{x=0}\right]$$

where $P_n(x) = p_{no} e^{(qV_{EB})/kT} \left[1\text{-}(x/W)\right]$

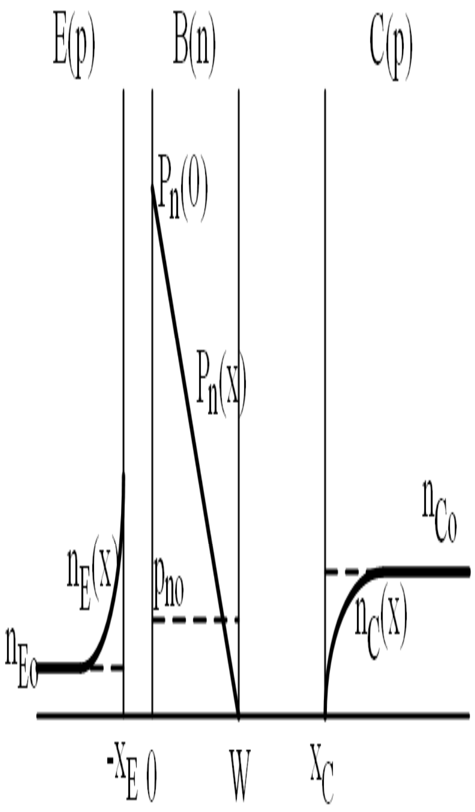
$$I_{Ep} \approx \frac{qAD_p p_{no}}{W} e^{(qV_{EB})/kT}$$

The hole current collected by C at x=W is

$$I_{Cp} = A\left[-qD_p \frac{dP_n(x)}{dx}\bigg|_{x=W}\right] \approx \frac{qAD_p p_{no}}{W} e^{(qV_{EB})/kT}$$

$$I_{Ep} = I_{Cp} \text{ for } \frac{W}{L_p} << 1 \text{ (i.e. when B is narrow)}$$

Distribution of the minority carriers in an active mode pnp transistor



I_{En} is produced by the flow of electrons from B to E.

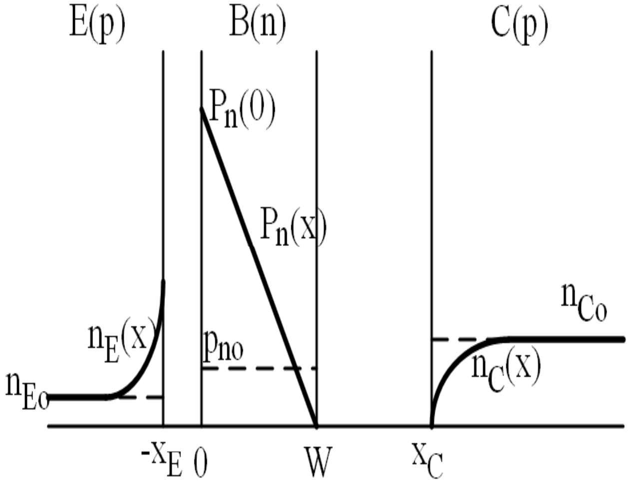
$$I_{En} = A\left[qD_E \frac{dn_E}{dx}\bigg|_{x=-x_E} \right]$$

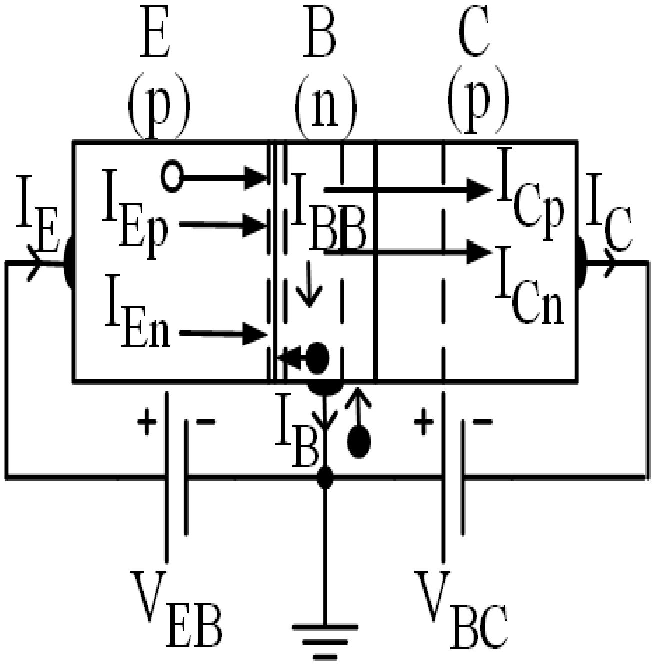
$$= \frac{qAD_E n_{Eo}}{L_E}\left[e^{(qV_{EB})/kT} - 1 \right]$$

L_E is the diffusion length of the electron in the E.

D_E is the diffusion constant for the electron in E.

Distribution of the minority carriers in an active mode pnp transistor





I_{Cn} is produced by the flow of electrons from C to B.

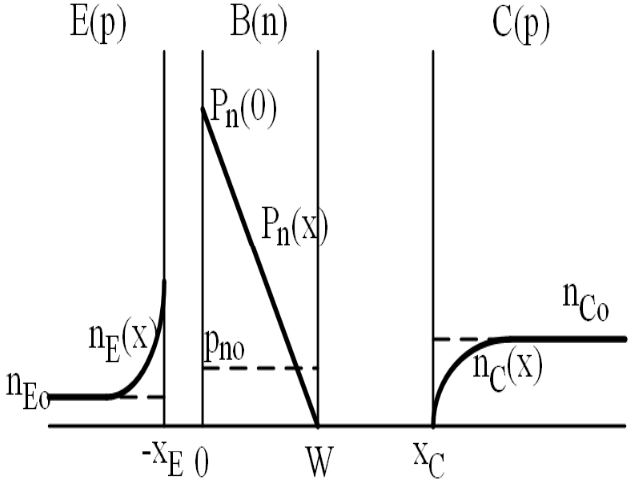
$$I_{Cn} = A\left[qD_C \left.\frac{dn_C}{dx}\right|_{x=x_C} \right]$$

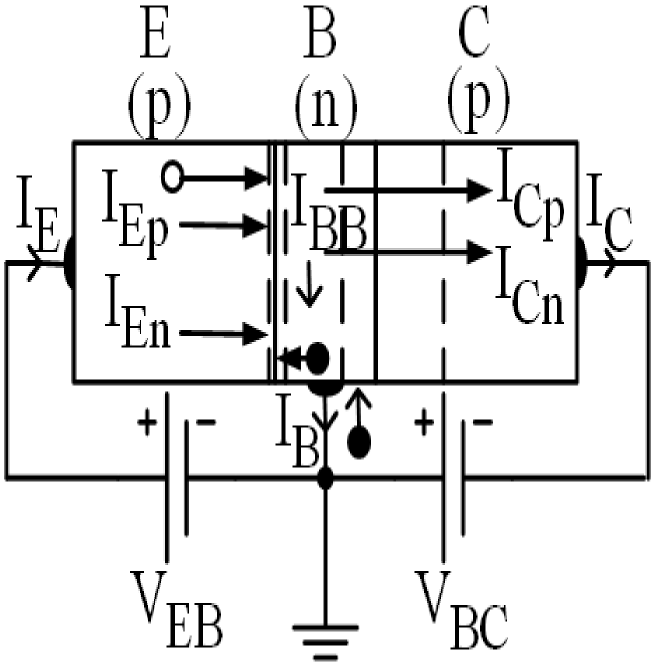
$$= \frac{qAD_C n_{Co}}{L_C}$$

L_C is the diffusion length of the electron in the C.

D_C is the diffusion constant for the electron in C.

Distribution of the minority carriers in an active mode pnp transistor





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

$$= \frac{qAD_p p_{no}}{W} e^{(qV_{EB})/kT} + \frac{qAD_E n_{Eo}}{L_E}\left[e^{(qV_{EB})/kT} - 1\right]$$

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

$$= \frac{qAD_p p_{no}}{W} e^{(qV_{EB})/kT} + \frac{qAD_C n_{Co}}{L_C}$$

$$I_B = I_E - I_C$$

$$\frac{qAD_E n_{Eo}}{L_E}\left[e^{(qV_{EB})/kT} - 1\right] - \frac{qAD_C n_{Co}}{L_C}$$

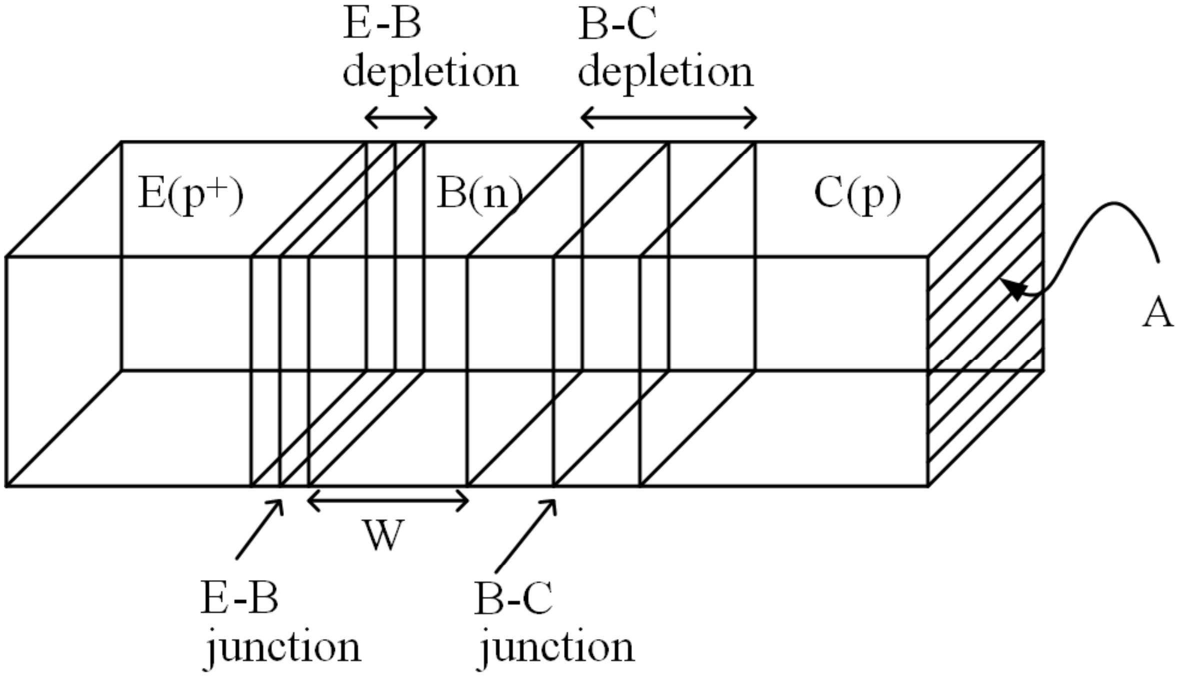
- **The current in each terminal (E,B and C) is determined mostly by the minority carrier distribution in B.**
- **I_C is independent of V_{BC} as long as the B-C junction is rb.**
- **If it is assumed that there is no recombination in B, $I_{EP} = I_{CP}$. Hence,**

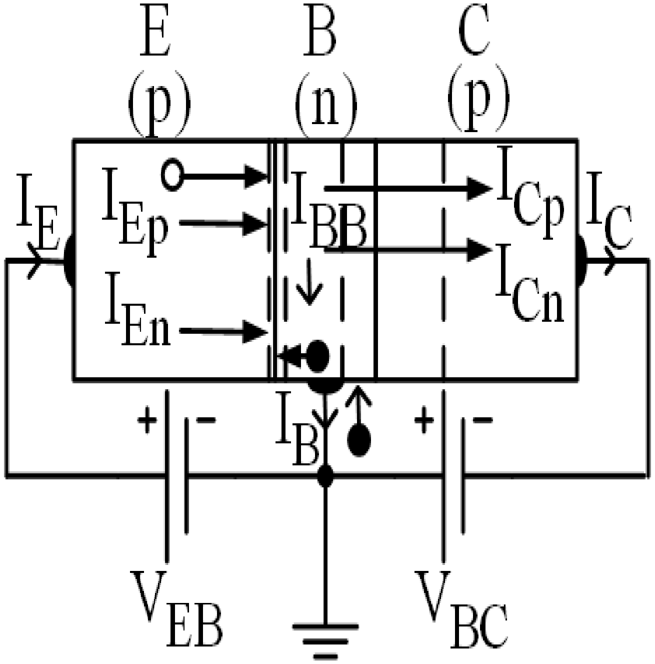
  $I_{BB} = I_{Ep} - I_{Cp} = 0$

  $I_B = I_{BB} + I_{En} – I_{Cn} = I_{En} – I_{Cn}$

QUESTION

The p^+-n-p transistor has 10^{19} , 10^{17} and 5x 10^{15} cm^{-3} impurity density in each E, B and C, respectively. The lifetime is 10^{-8} , 10^{-7} and 10^{-6} s. Assume that the cross-section area, A = 0.05 mm^2 and the E-B junction is fb by a 0.6 V. Determine the common-base (CB) current gain, α_o . Other device parameters are D_E = 1 cm^2/s, D_B = 10 cm^2/s, D_C = 2 cm^2/s, intrinsic electron-hole pair density = 9.65x10^9 cm^{-3} and W = 0.5 µm.





$$\alpha_o = \frac{I_{Cp}}{I_E}$$

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

$$= qA\left\{\frac{D_p p_{no}}{W} e^{(qV_{EB})/kT} + \frac{D_E n_{Eo}}{L_E}\left[e^{(qV_{EB})/kT} - 1\right]\right\}$$

$$I_{Cp} = \frac{qAD_p p_{no}}{W} e^{(qV_{EB})/kT}$$

D_p = diffusion constant of hole in B = 10 cm^2/s

p_{no} = hole minority carriers in B during equilibrium

$p_{no} = n_i^2/N_B = (9.65x10^9)^2/10^{17}$ = 931.225 cm^{-3}

D_E = electron diffusion coefficient in E = 1 cm^2/s

n_{Eo} = electron minority carrier in E during equilibrium

$n_{Eo} = n_i^2/N_E = (9.65x10^9)^2/10^{19}$ = 9.3122 cm^{-3}

L_E = electron diffusion length in E $= \sqrt{D_E \tau_E} = \sqrt{1\,cm^2/s\left(10^{-8}\,s\right)} = 10^{-4}\,cm$

Boltzmann constant $\bar{k} = 1.381 \times 10^{-23}\ J/\,^oK$

$$k = 8.620 \times 10^{-5}\ eV/\,^oK$$

$$I_{Cp} = I_{Ep} = \frac{qAD_p p_{no}}{W} e^{(qV_{EB})/kT}$$

$$= \frac{\left(1.6x10^{-19}C\right)\left(0.05x10^{-2}cm^2\right)\left(10cm^2/s\right)\left(931.225cm^{-3}\right)}{\left(0.5x10^{-4}cm\right)} e^{(qV_{EB})/kT}$$

$$I_{Cp} = I_{Ep} = 1.49\text{x}10^{-14}\ \text{x}1.1505\text{x}10^{10}\ \text{A}$$

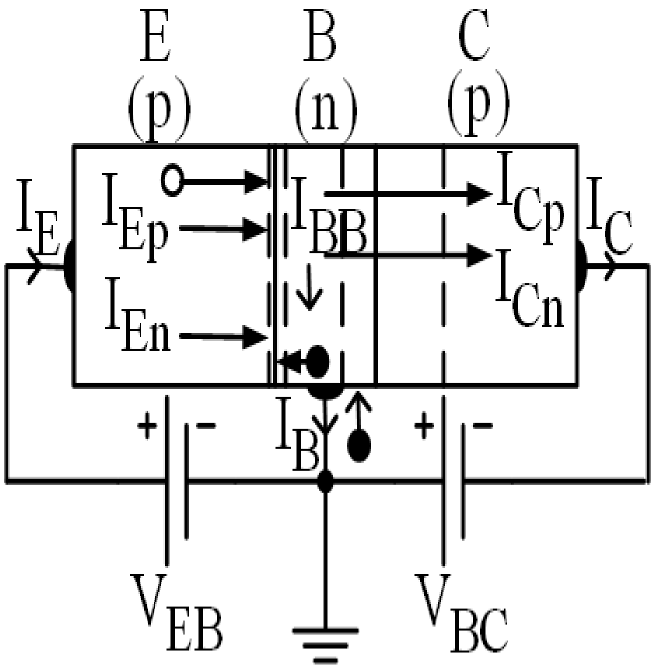
$$= 1.7142\text{x}10^{-4}\ \text{A}$$

$$I_{En} = \frac{qAD_E n_{Eo}}{L_E}\left[e^{(qV_{EB})/kT} - 1\right]$$

$$= \frac{\left(1.6\text{x}10^{-19}\text{C}\right)\left(0.05\text{x}10^{-2}\text{cm}^2\right)\left(1\text{cm}^2/\text{s}\right)\left(9.3122\text{cm}^{-3}\right)}{\left(10^{-4}\text{cm}\right)}\left(1.1505\text{x}10^{10} - 1\right)$$

$$= 8.5709\text{x}10^{-8}\ \text{A}$$

$$\alpha_o = \frac{I_{Cp}}{I_E} = \frac{1.7142\text{x}10^{-4}}{1.715\text{x}10^{-4}} = 0.9995$$



Emitter efficiency, $\gamma = I_{Ep} / (I_{Ep} + I_{En})$

$= I_{Ep} / I_E$

In the case of narrow Base, $I_{Ep} = I_{Cp}$

Thus, $\gamma = \alpha_o$.

$$\gamma = \frac{I_{Ep}}{I_E}$$

$$= \frac{\dfrac{qAD_p p_{no}}{W} e^{(qV_{EB})/kT}}{qA\left\{\dfrac{D_p p_{no}}{W} e^{(qV_{EB})/kT} + \dfrac{D_E n_{Eo}}{L_E}\left[e^{(qV_{EB})/kT} - 1\right]\right\}}$$

$$= \frac{\dfrac{D_p p_{no}}{W}}{\left\{\dfrac{D_p p_{no}}{W} + \dfrac{D_E n_{Eo}}{L_E}\right\}}$$

$$= \frac{1}{\left\{1 + \dfrac{D_E}{D_p}\dfrac{n_{Eo}}{p_{no}}\dfrac{W}{L_E}\right\}}$$

$$n_{Eo} = \frac{n_i^2}{N_E}, p_{no} = \frac{n_i^2}{N_B}, \therefore \gamma = \frac{1}{\left\{1 + \dfrac{D_E}{D_p}\dfrac{N_B}{N_E}\dfrac{W}{L_E}\right\}}$$

$$\gamma = \frac{1}{\left\{1 + \frac{D_E}{D_p}\frac{N_B}{N_E}\frac{W}{L_E}\right\}}$$

- **To increase the emitter efficiency, γ, N_B/N_E has to be low. This indicates that E has to be doped higher than B. This is the reason why E is represented by p^+ for the p^+-n-p transistor.**

- **To increase γ, the width of the B, W, should be small as compared to the diffusion length of the electrons in the E.**

BJT CIRCUIT CONFIGURATIONS

3 basic configurations:

1. **Common Emitter (CE)**
2. **Common Collector (CC)**
3. **Common Base (CB)**

All transistor circuits, no matter how complex they are, are based on either one or combinations of 2 or all of these configurations.

- **Common Emitter (CE)**

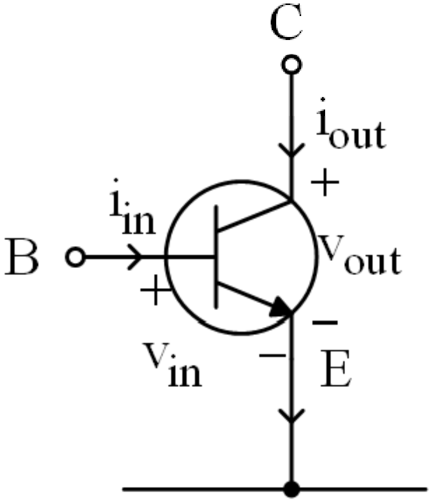
  E is the common point for both the input and output signals. Input signal is applied to B and output is at C. E is AC ground.

- **Common Collector (CC)**

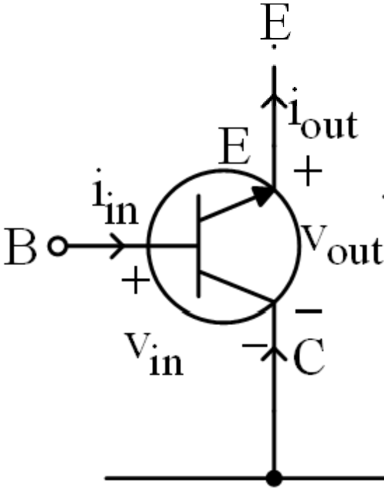
  C is the common point for both the input and output signals. Input signal is applied to B and output is at E. C is AC ground.

- **Common Base (CB)**

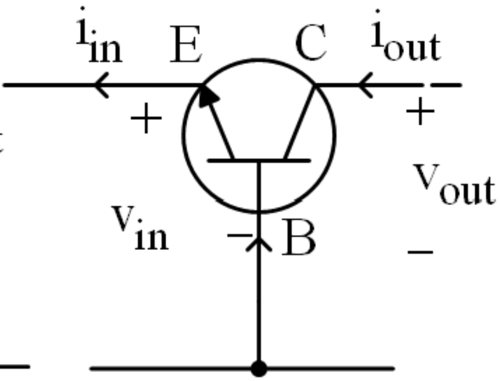
  B is the common point for both the input and output signals. Input signal is applied to E and output is at C. B is AC ground.



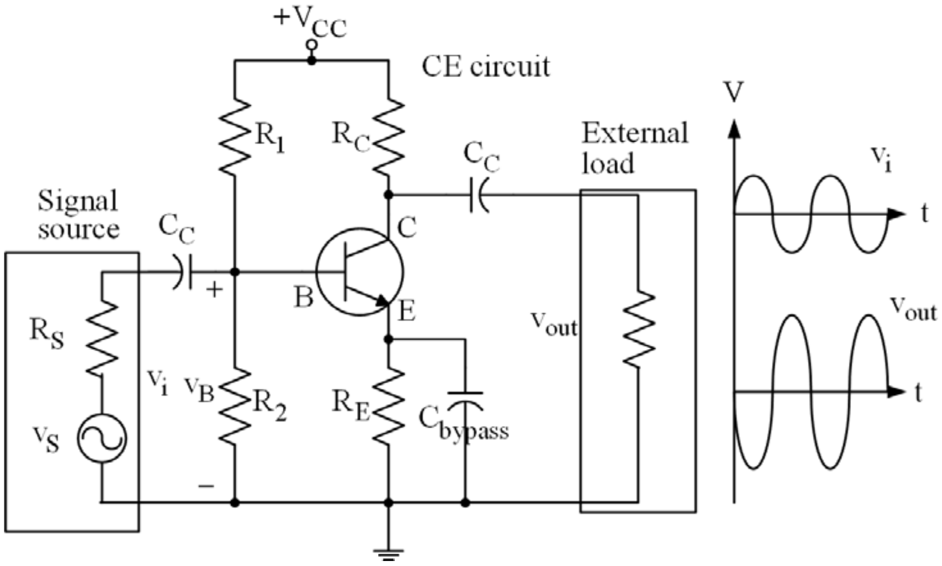
CE



CC



CB


+V_CC
CE circuit
R1
RC
CC
External load
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Signal source
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C
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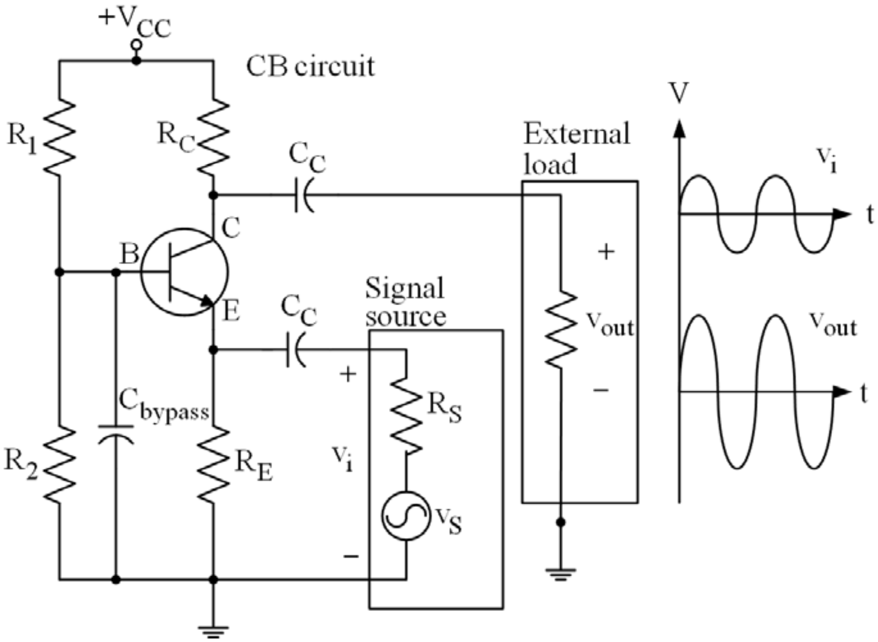
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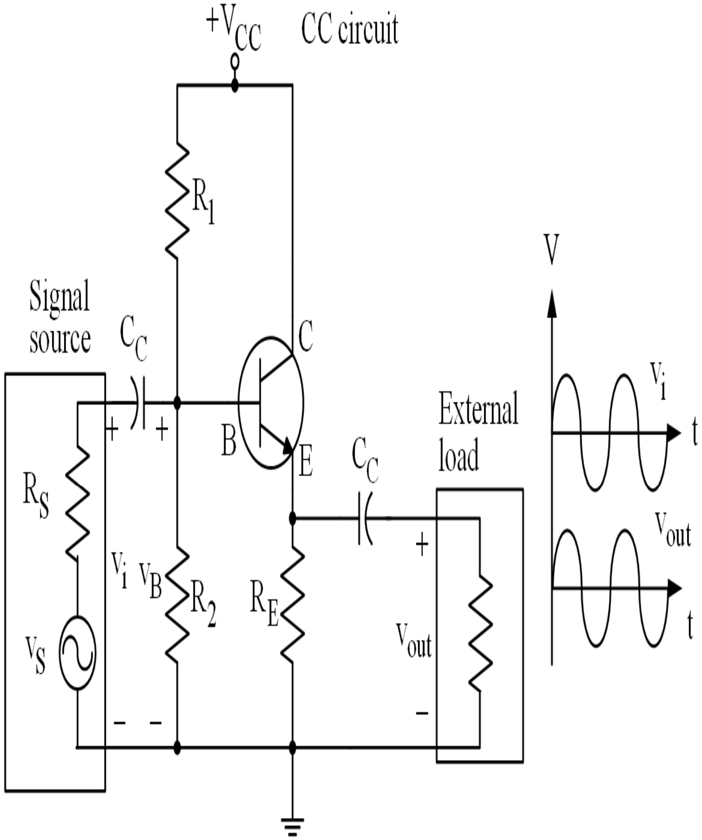
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