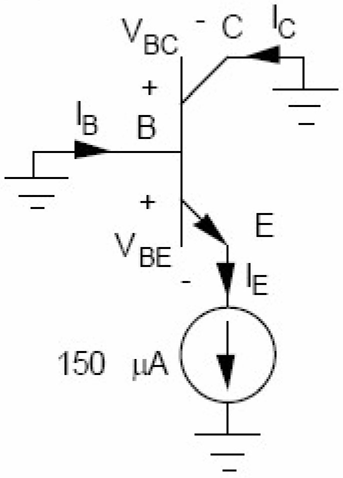
5.7



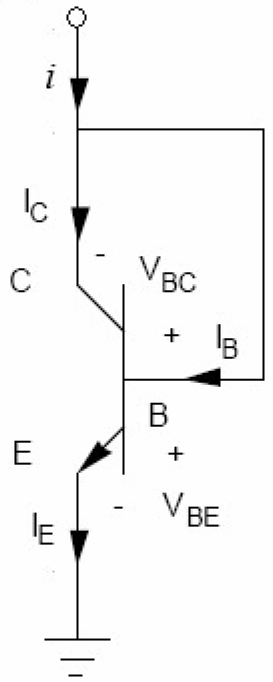

npn transistor

For $V_{BC} = 0$, $I_E = I_S\left(1+\dfrac{1}{\beta_F}\right)\left[\exp\left(\dfrac{V_{BE}}{V_T}\right)-1\right]$ | $I_B = \dfrac{I_E}{\beta_F+1}$ | $I_C = \beta_F I_B$

$I_E = 150\ \mu A$ | $I_B = \dfrac{150\mu A}{101} = 1.49\ \mu A$ | $I_C = \dfrac{100}{101}150\mu A = 149\ \mu A$

$$V_{BE} = V_T \ln\left(\frac{\beta_F}{\beta_F+1}\frac{I_E}{I_S}+1\right) = 0.025V\ln\left(\frac{100}{101}\frac{150\mu A}{2\,fA}+1\right) = 0.626\ \text{V}$$

5.9




Remember diode equation is :

$$i_D = I_S\left[\exp\left(\frac{v_D}{nV_T}\right)-1\right]$$

*Using* $v_{BC} = 0$ in following transport model equation

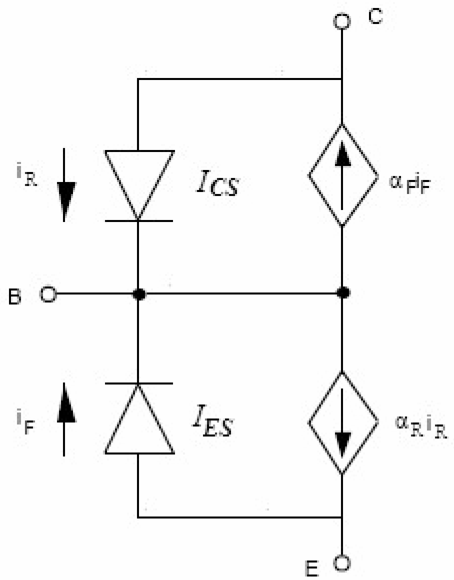
$$i_E = I_S\left[\exp\left(\frac{v_{BE}}{V_T}\right) - \exp\left(\frac{v_{BC}}{V_T}\right)\right] + \frac{I_S}{\beta_F}\left[\exp\left(\frac{v_{BE}}{V_T}\right)-1\right]$$

and recognizing that $i = i_C + i_B = i_E$ :

$i = i_E = I_S\left(1+\dfrac{1}{\beta_F}\right)\left[\exp\left(\dfrac{v_{BE}}{V_T}\right)-1\right]$, and the reverse saturation current

of the diode connected transistor is $I_S^{'} = I_S\left(1+\dfrac{1}{\beta_F}\right) = (2\,fA)\left(1+\dfrac{1}{100}\right) = 2.02\ fA$

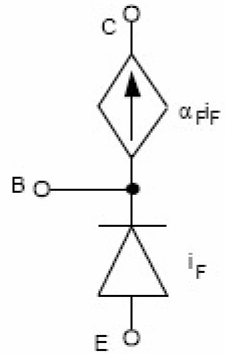
**5.29**




After substituting $V_{CB} = 0$ on following equations,

$$i_F = I_{ES}\left[\exp\left(\frac{v_{EB}}{V_T}\right) - 1\right] \qquad i_R = I_{CS}\left[\exp\left(\frac{v_{CB}}{V_T}\right) - 1\right]$$

the simplified version of Ebers Model is shown at below :




**5.39**

At $I_C = 5$ mA and $V_{CE} = 5$ V, $I_B = 60\mu A$ : $\beta_F = \frac{I_C}{I_B} = \frac{5mA}{60\mu A} = 83.3$

At $I_C = 7$ mA and $V_{CE} = 7.5$ V, $I_B = 80\mu A$ : $\beta_F = \frac{I_C}{I_B} = \frac{7mA}{80\mu A} = 87.5$

At $I_C = 10$ mA and $V_{CE} = 14$ V, $I_B = 100\mu A$ : $\beta_F = \frac{I_C}{I_B} = \frac{10mA}{100\mu A} = 100$

**5.58**

(a) pnp transistor with $V_{EB} = -3V$ and $V_{CB} = -3V$ is in *Cutoff*

Substituting $V_{EB}$, $V_{CB}$, $\beta_F$, $\beta_R$, and $I_S$ in the following equations :

$$i_C = I_S\left[\exp\left(\frac{v_{EB}}{V_T}\right) - \exp\left(\frac{v_{CB}}{V_T}\right)\right] - \frac{I_S}{\beta_R}\left[\exp\left(\frac{v_{CB}}{V_T}\right) - 1\right] \longrightarrow I_C = +\frac{I_S}{\beta_R} = \frac{10^{-15}A}{2} = 0.5\text{x}10^{-15} = 0.5\text{ fA}$$

$$i_E = I_S\left[\exp\left(\frac{v_{EB}}{V_T}\right) - \exp\left(\frac{v_{CB}}{V_T}\right)\right] + \frac{I_S}{\beta_F}\left[\exp\left(\frac{v_{BE}}{V_T}\right) - 1\right] \longrightarrow I_E = -\frac{I_S}{\beta_F} = \frac{10^{-15}A}{75} = 13.3\text{x}10^{-18} = 13.3\text{ aA}$$

$$i_B = \frac{I_S}{\beta_F}\left[\exp\left(\frac{v_{EB}}{V_T}\right) - 1\right] + \frac{I_S}{\beta_R}\left[\exp\left(\frac{v_{CB}}{V_T}\right) - 1\right] \longrightarrow I_B = -I_S\left(\frac{1}{\beta_F} + \frac{1}{\beta_R}\right) = 10^{-15}A\left(\frac{1}{75} + \frac{1}{2}\right) = 0.513x10^{-15} = 0.513\,fA$$

(b) npn transistor with $V_{BE} = -5V$ and $V_{BC} = -5V$ is in *Cutoff*

Substituting $V_{EB}$, $V_{CB}$, $\beta_F$, $\beta_R$, and $I_S$ in the following equations :

$$i_C = I_S\left[\exp\left(\frac{v_{BE}}{V_T}\right) - \exp\left(\frac{v_{BC}}{V_T}\right)\right] - \frac{I_S}{\beta_R}\left[\exp\left(\frac{v_{BC}}{V_T}\right) - 1\right] \longrightarrow I_C = +\frac{I_S}{\beta_R} = \frac{10^{-15}A}{2} = 0.5\text{x}10^{-15} = 0.5\text{ fA}$$

$$i_E = I_S\left[\exp\left(\frac{v_{BE}}{V_T}\right) - \exp\left(\frac{v_{BC}}{V_T}\right)\right] + \frac{I_S}{\beta_F}\left[\exp\left(\frac{v_{BE}}{V_T}\right) - 1\right] \longrightarrow I_E = -\frac{I_S}{\beta_F} = \frac{10^{-15}A}{75} = 13.3\text{x}10^{-18} = 13.3\text{ aA}$$

$$i_B = \frac{I_S}{\beta_F}\left[\exp\left(\frac{v_{BE}}{V_T}\right) - 1\right] + \frac{I_S}{\beta_R}\left[\exp\left(\frac{v_{BC}}{V_T}\right) - 1\right] \longrightarrow I_B = -I_S\left(\frac{1}{\beta_F} + \frac{1}{\beta_R}\right) = 10^{-15}A\left(\frac{1}{75} + \frac{1}{2}\right) = 0.513x10^{-15} = 0.513fA$$

The currents are the same as in part (a).

**5.61**

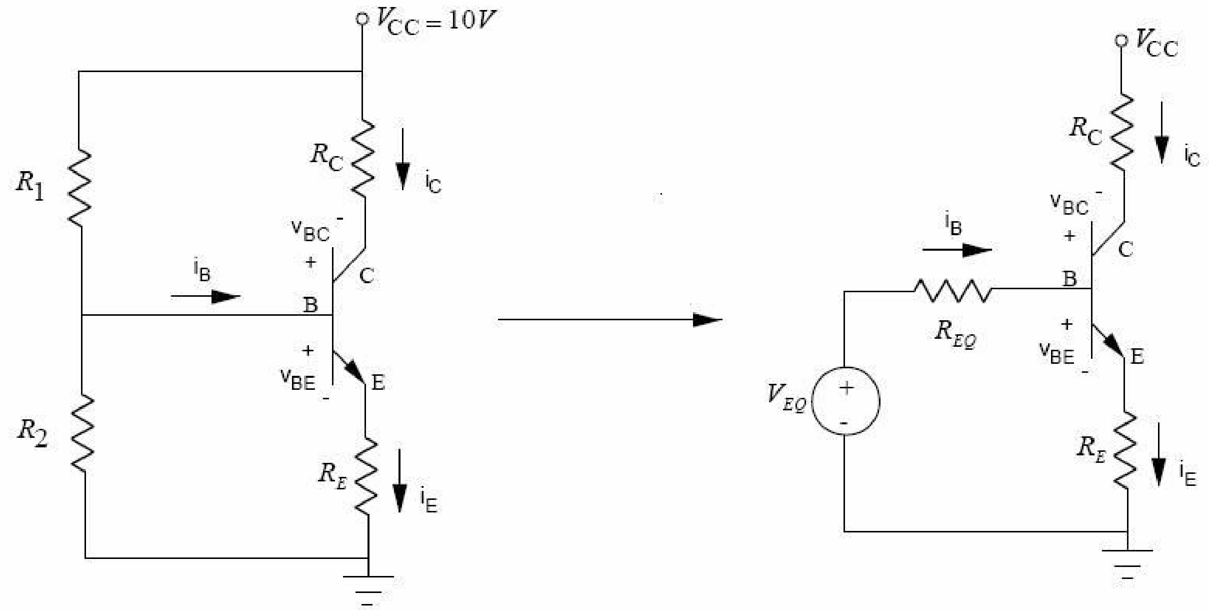
A pnp transistor with $V_{EB} = 0.7V$ and $V_{CB} = -0.7V \Rightarrow$ Forward - active region

$$\beta_F = \frac{I_C}{I_B} = \frac{2.5mA}{0.05mA} = 50$$

$$i_C = I_S\left[\exp\left(\frac{v_{EB}}{V_T}\right) - \underbrace{\cancel{\exp\left(\frac{v_{CB}}{V_T}\right)}}_{\cong 0}\right] - \frac{I_S}{\beta_R}\left[\underbrace{\cancel{\exp\left(\frac{v_{CB}}{V_T}\right)}}_{\cong 0} - 1\right] \longrightarrow I_C = I_S \exp\left(\frac{V_{EB}}{V_T}\right) \longrightarrow I_S = \frac{2.5mA}{\exp\left(\frac{0.7V}{0.025V}\right)} = 1.73\ fA$$

$$\left(I_S \exp\left(\frac{v_{EB}}{V_T}\right) \gg \frac{I_S}{\beta_R}\right)$$

**5.82**




$(a)$

$$V_{EQ} = \frac{R_2}{R_2 + R_1} V_{CC} = \frac{36k\Omega}{36k\Omega + 68k\Omega} 10V = 3.462V \quad \Big| \quad R_{EQ} = R_2 \| R_1 \qquad R_{EQ} = 36k\Omega \| 68k\Omega = 23.54k\Omega$$

$$I_B = \frac{V_{EQ} - V_{BE}}{R_{EQ} + (\beta_F + 1) R_E}$$

$$I_B = \frac{3.462 - 0.7}{23.54 + (50+1)33} \frac{V}{k\Omega} = 1.618\mu A \quad \Big| \quad I_C = \beta_F I_B \qquad I_C = 50 I_B = 80.9\ \mu A \quad \Big| \quad I_E = (\beta_F + 1) I_B \qquad I_E = 51 I_B = 82.5\ \mu A$$

$$V_{CE} = V_{CC} - R_C I_C - R_E I_E$$

$$V_{CE} = 10 - 43000 I_C - 33000 I_E = 3.797V \quad \Big| \quad \text{Q-point}: \ (\underset{I_C}{80.9\ \mu A}, \underset{V_{CE}}{3.80\ V})$$

$(b)$

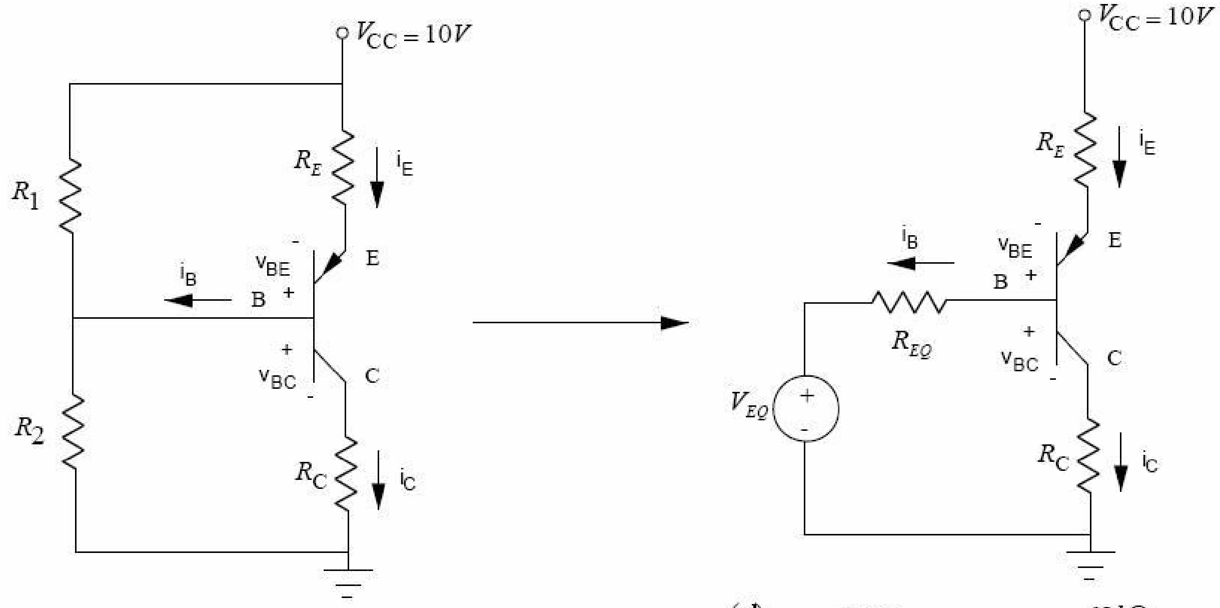
$$R_1 = \frac{68k\Omega}{5} = 13.6k\Omega \quad R_2 = \frac{36k\Omega}{5} = 7.2k\Omega \quad R_E = \frac{33k\Omega}{5} = 6.6k\Omega \quad R_C = \frac{43k\Omega}{5} = 8.6k\Omega$$

$$V_{EQ} = \frac{7.2k\Omega}{7.2k\Omega + 13.6k\Omega} 10V = 3.462V \quad \Big| \quad R_{EQ} = 7.2k\Omega \| 13.6k\Omega = 4.708k\Omega$$

$$I_B = \frac{3.462 - 0.7}{4.708 + (50+1)6.6} \frac{V}{k\Omega} = 8.092\mu A \quad \Big| \quad I_C = 50 I_B = 404.6\mu A \quad \Big| \quad I_E = 51 I_B = 412.7\ \mu A$$

$$V_{CE} = 10 - 8600 I_C - 6600 I_E = 3.7976V \quad \Big| \quad \text{Q-point}: \ (405\ \mu A, 3.80\ V)$$

**5.82**




$(c)$

$$V_{EQ} = \frac{68k\Omega}{36k\Omega + 68k\Omega}10V = 6.538V \quad | \quad R_{EQ} = 36k\Omega \| 68k\Omega = 23.54k\Omega$$

$$I_B = \frac{V_{CC} - V_{EB} - V_{EQ}}{R_{EQ} + (\beta_F + 1) R_E} \qquad I_C = \beta_F I_B \qquad I_E = (\beta_F + 1) I_B$$

$$I_B = \frac{10 - 0.7 - 6.538}{23.54 + (50+1)33} \frac{V}{k\Omega} = 1.618\mu A \qquad I_C = 50 I_B = 80.9\ \mu A \qquad I_E = 51 I_B = 82.5\ \mu A$$

$$V_{EC} = 10 - 33000 I_C - 43000 I_E = 3.797V \ | \ \text{Q-point}: (80.9\ \mu\text{A}, 3.80\ \text{V})$$

$(d)$ $R_1 = \frac{36k\Omega}{5} = 7.2k\Omega \quad R_2 = \frac{68k\Omega}{5} = 13.6k\Omega \quad R_E = \frac{33k\Omega}{5} = 6.6k\Omega \quad R_C = \frac{43k\Omega}{5} = 8.6k\Omega$

$$V_{EQ} = \frac{13.6k\Omega}{7.2k\Omega + 13.6k\Omega}10V = 6.538V \quad | \quad R_{EQ} = 7.2k\Omega \| 13.6k\Omega = 4.708k\Omega$$

$$I_B = \frac{10 - 0.7 - 6.538}{4.708 + (50+1)6.6} \frac{V}{k\Omega} = 8.092\mu A \ | \ I_C = 50 I_B = 404.6\mu A \ | \ I_E = 51 I_B = 412.7\ \mu A$$

$$V_{EC} = 10 - 6600 I_E - 8600 I_C = 3.7976V \ | \ \text{Q-point}: (405\ \mu\text{A}, 3.80\ \text{V})$$