CHAPTER 1:

1-

(a)

The doping density in the p-type material is

$$N_A = 8\times 10^{15} \text{ atoms / cm}^3$$

The doping density in the n-type material is

$$N_D = 10^{17} \text{ atoms / cm}^3$$

The built in potential in a plane-abrupt pn junction is

$$\psi_0 = V_T \ln \frac{N_A\ N_D}{n_i^2} \ \dots\dots\dots\dots \ (1)$$

Where $V_T = \dfrac{K_T}{q}$

$$V_T = 26 \text{ mV at } 300^\circ\text{K}$$

n_i is the intrinsic carrier concentration in pure semiconductor

$$n_i = 1.5\times 10^{10}\ \text{cm}^{-3} \quad \text{at } 300^\circ\text{K}$$

By substituting all values in equation (1) we can write

$$\psi_0 = V_T \ln \frac{N_A\ N_D}{n_i^2}$$

$$\psi_0 = \left(26\times 10^{-3}\right)\ln\left[\frac{\left(8\times 10^{15}\right)\left(10^{17}\right)}{\left(1.5\times 10^{10}\right)^2}\right]$$

$$\psi_0 = \left(26\times 10^{-3}\right)(28.8995)$$

$$\psi_0 = 0.751387$$

$$\boxed{\psi_0 = 751\,\mathrm{mV}}$$

The depletion layer depth in the p-type region is

$$W_1 = \left[\frac{2\varepsilon\left(\psi_0 + V_R\right)}{qN_A\left(1+\frac{N_A}{N_D}\right)}\right]^{\frac{1}{2}} \quad \text{................} \ (2)$$

q is the electron charge 1.6×10^{-19} coulomb

ε is the permittivity of the silicon 1.04×10^{-12} farad / cm

$\left(\psi_0 + V_R\right)$ is the total voltage across the junction

$\psi_0 + V_R = 751\times10^{-3} + 5$

$\psi_0 + V_R = 5.751\mathrm{V}$

Substitute all these values in equation (2)

$$W_1 = \left[\frac{2\left(1.04\times10^{-12}\right)\left(5.751\right)}{\left(1.6\times10^{-19}\right)\left(8\times10^{15}\right)\left(1+\frac{8\times10^{15}}{10^{17}}\right)}\right]^{\frac{1}{2}}$$

$$W_1 = \left[\frac{1.196208 \times 10^{-11}}{1.3824 \times 10^{-3}} \right]^{\frac{1}{2}}$$

$$W_1 = \left[8.653125 \times 10^{-9} \right]^{\frac{1}{2}}$$

$$W_1 = 9.3022 \times 10^{-5}$$

$$\boxed{W_1 = 0.93 \mu\text{m}}$$

The depletion layer depth in the n-type region is

$$W_2 = \left[\frac{2\varepsilon(\psi_0 + V_R)}{qN_D\left(1 + \frac{N_D}{N_A}\right)} \right]^{\frac{1}{2}}$$

$$W_2 = \left[\frac{2(1.04 \times 10^{-12})(5.751)}{(1.6 \times 10^{-19})(10^{17})\left(1 + \frac{10^{17}}{8 \times 10^{15}}\right)} \right]^{\frac{1}{2}}$$

$$W_2 = \left[\frac{1.158768 \times 10^{-11}}{0.216} \right]^{\frac{1}{2}}$$

$$W_2 = \left[5.364666667\times10^{-11}\right]^{\frac{1}{2}}$$

$$W_2 = 7.324\times10^{-6}$$

$$\boxed{W_2 = 7.3\mu\text{m}}$$

The maximum field that occurs is

$$\mathcal{E}_{\max} = -\frac{qN_A W_1}{\varepsilon}$$

$$\mathcal{E}_{\max} = -\frac{\left(1.6\times10^{-19}\right)\left(8\times10^{15}\right)\left(0.93\times10^{-4}\right)}{1.04\times10^{-12}}$$

$$\mathcal{E}_{\max} = -114461.5385$$

$$\boxed{\mathcal{E}_{\max} = -11.44\times10^{4}\ \text{V/cm}}$$

(b)

For zero external bias voltage

$$\psi_0 + V_R = 5.751$$

$$\psi_0 + 5 = 5.751$$

$$\psi_0 = 5.751 - 5$$

$$\psi_0 = 0.751$$

Now the depletion layer depth in the p-type region is

$$W_{1(\text{zero bias})} = W_1\left(\sqrt{\frac{\psi_0}{\psi_0 + V_R}}\right)$$

$$W_{1(\text{zero bias})} = \left(0.93\times10^{-6}\right)\left(\sqrt{\frac{0.751}{0.751+5}}\right)$$

$$W_{1(\text{zero bias})} = 0.336\times10^{-6}$$

$$\boxed{W_{1(\text{zero bias})} = 0.336\,\mu\text{m}}$$

Now the depletion layer depth in the n-type region is

$$W_{2(\text{zero bias})} = W_2\left(\sqrt{\frac{\psi_0}{\psi_0+V_R}}\right)$$

$$W_{2(\text{zero bias})} = \left(7.3\times10^{-6}\right)\left(\sqrt{\frac{0.751}{0.751+5}}\right)$$

$$\boxed{W_{2(\text{zero bias})} = 2.64\,\mu\text{m}}$$

For zero external bias voltage maximum field occurs

$$\xi_{\max(\text{zero bias})} = \xi_{\max}\times\frac{W_{1(\text{zero bias})}}{W_1}$$

$$\xi_{\max(\text{zero bias})} = -11.44\times10^{4}\times\frac{0.336\times10^{-6}}{0.93\times10^{-6}}$$

$$\xi_{\max(\text{zero bias})} = -41331.6129$$

$$\boxed{\xi_{\max(\text{zero bias})} = -4.133\times10^{4}\,\text{V/cm}}$$

Given forward bias voltage $= 0.3\text{V}$
Built-in potential for this forward voltage
$\psi_0 - 0.3 = 0.751 - 0.3$
$\psi_0 - 0.3 = 0.451\text{V}$
Now the depletion layer depth in the p-type region is

$$W_{1(0.3\text{V forward})} = W_1\left(\sqrt{\frac{0.451}{5.751}}\right)$$

$$W_{1(0.3\text{V forward})} = \left(0.93\times10^{-6}\right)\left(\sqrt{\frac{0.451}{5.751}}\right)$$

$$W_{1(0.3\text{V forward})} = 0.2604\times10^{-6}$$

$$\boxed{W_{1(0.3\text{V forward})} = 0.26\,\mu\text{m}}$$

The depletion layer depth in the n-type region is

$$W_{2(0.3\text{V forward})} = W_2\left(\sqrt{\frac{0.451}{5.751}}\right)$$

$$W_{2(0.3\text{V forward})} = \left(7.3\times10^{-6}\right)\left(\sqrt{\frac{0.451}{5.751}}\right)$$

$$W_{2(0.3\text{V forward})} = 2.044\times10^{-6}$$

$$\boxed{W_{2(0.3\text{V forward})} = 2.044\,\mu\text{m}}$$

The maximum field that occurs in 0.3V forward bias

$$\xi_{\max(0.3\text{V forward})} = \xi_{\max}\times\frac{W_{1(0.3\text{V forward})}}{W_1}$$

$$\xi_{\max(0.3\text{V forward})} = -11.44\times10^{4}\times\frac{0.26\times10^{-6}}{0.93\times10^{-6}}$$

$$\xi_{\max(0.3\text{V forward})} = -31982.7957$$

$$\boxed{\xi_{\max(0.3\text{V forward})} = -3.198\times10^{4}\,\text{V/cm}}$$

2-

The zero bias junction capacitance is

$$C_{j(\text{zero})} = A\left[\frac{q \in N_A N_D}{2\left(N_A + N_D\right)}\right]^{\frac{1}{2}} \frac{1}{\sqrt{\psi_0}} \qquad \ldots\ldots\ldots\ldots \ (1)$$

Given parameters

$q = 1.6\times10^{-19}$ columb

$\varepsilon = 1.04\times10^{-12}$ farad/cm

The doping density in the p-type material is $N_A = 8\times10^{15}$ atoms / cm^3

The doping density in the n-type material is $N_D = 10^{17}$ atoms / cm^3

The built in potential of the depletion layer is $\psi_0 = 0.751$ V

The junction area $A = 2\times10^{-5}\,\text{cm}^2$

Now equation (1) becomes

$$C_{j(\text{zero})} = 2\times10^{-5}\left[\frac{1.6\times10^{-19}\times1.04\times10^{-12}\times8\times10^{15}\times10^{17}}{2\left(8\times10^{15}+10^{17}\right)}\right]$$

$$C_{j(\text{zero})} = 2\times10^{-5}\left[\frac{133.12}{2.16\times10^{17}}\right]^{\frac{1}{2}}\times\frac{1}{\sqrt{0.751}}$$

$$C_{j(\text{zero})} = 5.72934\times10^{-13}\text{F}$$

$$C_{j(\text{zero})} = 5.72934\times10^{-13}\text{F}$$

$$\boxed{C_{j(\text{zero})} = 0.57\text{pF}}$$

Given reverse bias voltage $V_R = 5\text{V}$

Reverse bias junction capacitance is

$$C_{j(\text{reverse})} = A\left[\frac{q \in N_A N_D}{2(N_A + N_D)}\right]^{\frac{1}{2}} \frac{1}{\sqrt{\psi_0 + V_R}} \ldots\ldots\ldots\ldots \ (2)$$

$$\frac{(2)}{(1)} \Rightarrow \frac{C_{j(\text{reverse})}}{C_{j(\text{zero})}} = \frac{A\left[\frac{q \in N_A N_D}{2(N_A + N_D)}\right]^{\frac{1}{2}} \frac{1}{\sqrt{\psi_0 + V_R}}}{A\left[\frac{q \in N_A N_D}{2(N_A + N_D)}\right]^{\frac{1}{2}} \frac{1}{\sqrt{\psi_0}}}$$

$$\frac{C_{j(\text{reverse})}}{C_{j(\text{zero})}} = \frac{\frac{1}{\sqrt{\psi_0 + V_R}}}{\frac{1}{\sqrt{\psi_0}}}$$

$$\frac{C_{j(\text{reverse})}}{C_{j(\text{zero})}} = \frac{1}{\sqrt{1 + \frac{V_R}{\psi_0}}}$$

$$C_{j(\text{reverse})} = \frac{C_{j(\text{zero})}}{\sqrt{1 + \frac{V_R}{\psi_0}}}$$

$$C_{j(\text{reverse})} = \frac{0.57\times10^{-12}}{\sqrt{1+\frac{5}{0.751}}}$$

$$C_{j(\text{reverse})} = 2.05979\times10^{-13}\text{F}$$

$$\boxed{C_{j(\text{reverse})} = 0.2\text{pF}}$$

Given forward bias voltage $V_f = 0.3\text{V}$

Forward bias junction capacitance is

$$C_{j(\text{forward})} = A\left[\frac{q\in N_A N_D}{2(N_A+N_D)}\right]^{\frac{1}{2}} \frac{1}{\sqrt{\psi_0 - V_f}} \ldots\ldots\ldots\ldots(3)$$

$$\frac{(3)}{(1)} \Rightarrow \frac{C_{j(\text{forward})}}{C_{j(\text{zero})}} = \frac{A\left[\frac{q\in N_A N_D}{2(N_A+N_D)}\right]^{\frac{1}{2}} \frac{1}{\sqrt{\psi_0 - V_f}}}{A\left[\frac{q\in N_A N_D}{2(N_A+N_D)}\right]^{\frac{1}{2}} \frac{1}{\sqrt{\psi_0}}}$$

$$\frac{C_{j(\text{forward})}}{C_{j(\text{zero})}} = \frac{1}{\sqrt{1-\frac{V_f}{\psi_0}}}$$

$$C_{j(\text{forward})} = \frac{C_{j(\text{zero})}}{\sqrt{1-\frac{V_f}{\psi_0}}}$$

$$C_{j(\text{forward})} = \frac{0.57\times10^{-12}}{\sqrt{1-\frac{0.3}{0.751}}}$$

$$C_{j(\text{forward})} = 7.3554\times10^{-13}\text{F}$$

$$\boxed{C_{j(\text{forward})} = 0.74\text{pF}}$$

3-

The maximum electric field value in the depletion region is

$$\left|\xi_{\max}\right| = \left[\frac{2qN_A N_D V_R}{\varepsilon\left(N_A + N_D\right)}\right]^{\frac{1}{2}} \text{ .... (1)}$$

Given parameters

$q = 1.6\times10^{-19}$ columb

$\varepsilon = 1.04\times10^{-12}$ farad/cm

The doping density in the p-type material is $N_A = 8\times10^{15}$ atoms / cm^3

The doping density in the n-type material is $N_D = 10^{17}$ atoms / cm^3

The maximum electric field $\left|\xi_{\max}\right| = \xi_{\text{crit}} = 4\times10^5$ V/cm

Now equation (1) becomes

$$4\times10^5 = \left[\frac{2\times1.6\times10^{-19}\times8\times10^{15}\times10^{17}\times V_R}{1.04\times10^{-12}\left(8\times10^{15}+10^{17}\right)}\right]^{\frac{1}{2}}$$

$$4\times10^5 = \left[\frac{2.56\times10^{14}\times V_R}{112320}\right]^{\frac{1}{2}}$$

$$16\times10^{10} = \frac{2.56\times10^{14}\times V_R}{112320}$$

$$V_R = \frac{112320\times16\times10^{10}}{2.56\times10^{14}}$$

$$\boxed{V_R = 70.2\text{V}}$$

4-

The maximum electric field value in the depletion region is

$$|\xi_{\max}|=\left[\frac{2qN_AN_DV_R}{\varepsilon(N_A+N_D)}\right]^{\frac{1}{2}} \text{ .... (1)}$$

If junction curvature causes the maximum field at a practical junction to be 1.5 times the theoretical value, then we can write

$$|\xi_{\max}|=1.5\left[\frac{2qN_AN_DV_R}{\varepsilon(N_A+N_D)}\right]^{\frac{1}{2}} \text{ .... (2)}$$

Given that one side of the junction is much more heavily doped than the other.

$N_A \gg N_D$

$\xi_{\text{crit}}=3\times10^5$ V/cm

The break down voltage $V_R = 150\text{V}$

From equation (2) we can write

$$3\times10^5 = 1.5\left[\frac{2qN_AN_DV_R}{\varepsilon(N_A+N_D)}\right]^{\frac{1}{2}}$$

Squaring on both sides we have

$$9\times10^{10} = 2.25\left[\frac{2qN_AN_DV_R}{\varepsilon(N_A+N_D)}\right]$$

$$V_R = \left(\frac{9\times10^{10}}{2.25}\right)\left[\frac{\varepsilon(N_A+N_D)}{2qN_AN_D}\right]$$

Given that $N_A \gg N_D$, so we can modify above equation as below

$$V_R = \left(\frac{9\times10^{10}}{2.25}\right)\left[\frac{\varepsilon\left(N_A\right)}{2qN_AN_D}\right]$$

$$V_R = \left(\frac{9\times10^{10}}{2.25}\right)\left(\frac{\varepsilon}{2qN_D}\right)$$

$$N_D = \left(\frac{9\times10^{10}}{2.25}\right)\left(\frac{\varepsilon}{2qV_R}\right) \text{..........} (3)$$

By substituting $\varepsilon = 1.04\times10^{-12}$ farad/cm , $q = 1.6\times10^{-19}$ columb and $V_R = 150\text{V}$ in equation (3) we can get

$$N_D = \left(\frac{9\times10^{10}}{2.25}\right)\left(\frac{1.04\times10^{-12}}{2\left(1.6\times10^{-19}\right)(150)}\right)$$

$$N_D = \left(4\times10^{10}\right)(21666.66667)$$

$$N_D = 8.6666\times10^{14} \text{ atoms/cm}^3$$

$$\boxed{N_D = 8.67\times10^{14} \text{ atoms/cm}^3}$$

5-

Consider npn transistor

The collector doping density in the transistor is $N_D = 6\times10^{15}$ atoms/cm^3

The break down voltage

$$BV_{CBO} = \frac{\varepsilon\left(N_A + N_D\right)}{2qN_AN_D}\xi_{\text{crit}}^2 \text{ .... (1)}$$

Given that collector doping density (N_D) is much lesser than the base doping density (N_A)

i.e. $N_D << N_A$

Now equation (1) becomes

$$BV_{CBO} = \frac{\varepsilon\left(N_A\right)}{2qN_AN_D}\xi_{\text{crit}}^2$$

$$BV_{CBO} = \frac{\varepsilon}{2qN_D}\xi_{\text{crit}}^2 \text{ .... (2)}$$

By substituting $\varepsilon = 1.04\times10^{-12}$ farad/cm , $q = 1.6\times10^{-19}$ columb , $N_D = 6\times10^{15}$ atoms/cm^3 and $\xi_{\text{crit}} = 3\times10^5$ V/cm in equation (2) we can get

$$BV_{CBO} = \left(\frac{1.04\times10^{-12}}{2\left(1.6\times10^{-19}\right)\left(6\times10^{15}\right)}\right)\left(3\times10^5\right)^2$$

$$BV_{CBO} = \left(\frac{1.04\times10^{-12}}{1.92\times10^{-3}}\right)\left(9\times10^{10}\right)$$

$$BV_{CBO} = 48.75\text{V}$$

We have $BV_{CEO} = \dfrac{BV_{CBO}}{n\sqrt{\beta_F}}$ .... (3)

Given parameters:

$n = 4$,

$\beta_F = 200$

By substituting $n = 4$, $\beta_F = 200$ and $BV_{CBO} = 48.75\text{V}$ in equation (3), we can write

$$BV_{CEO} = \frac{48.75}{4\sqrt{200}}$$

$$BV_{CEO} = \frac{48.75}{3.7606}$$

$$BV_{CEO} = 12.9633$$

$$\boxed{BV_{CEO} = 13\text{V}}$$

6-

Consider *npn* transistor

The collector doping density in the transistor is $N_D = 10^{15}$ atoms/cm^3

The break down voltage

$$BV_{CBO} = \frac{\varepsilon\left(N_A + N_D\right)}{2qN_AN_D}\xi_{\text{crit}}^{\varepsilon 2} \dots\dots\dots\dots (1)$$

Given that collector doping density (N_D) is much lesser than the base doping density (N_A)

i.e. $N_D << N_A$

Now equation (1) becomes

$$BV_{CBO} = \frac{\varepsilon\left(N_A\right)}{2qN_AN_D}\xi_{\text{crit}}^{\varepsilon 2}$$

$$BV_{CBO} = \frac{\varepsilon}{2qN_D}\xi_{\text{crit}}^{\varepsilon 2} \dots\dots\dots\dots (2)$$

By substituting $\varepsilon = 1.04\times10^{-12}$ farad/cm , $q = 1.6\times10^{-19}$ columb , $N_D = 10^{15}$ atoms/cm^3 and $\xi_{\text{crit}}^{\varepsilon} = 3\times10^5$ V/cm in equation (2) we can get

$$BV_{CBO} = \left(\frac{1.04\times10^{-12}}{2\left(1.6\times10^{-19}\right)\left(10^{15}\right)}\right)\left(3\times10^5\right)^2$$

$$BV_{CBO} = \left(\frac{1.04\times10^{-12}}{3.2\times10^{-4}}\right)\left(9\times10^{10}\right)$$

$$BV_{CBO} = 292.5\text{V}$$

We have $BV_{CEO} = \dfrac{BV_{CBO}}{n\sqrt{\beta_F}} \dots\dots\dots (3)$

Given parameters:

$n = 4$,

$\beta_F = 400$

By substituting $n = 4$, $\beta_F = 400$ and $BV_{CBO} = 292.5\text{V}$ in equation (3), we can write

$$BV_{CEO} = \frac{292.5}{4\sqrt{400}}$$

$$BV_{CEO} = \frac{292.5}{4.472}$$

$$BV_{CEO} = 65.405\text{V}$$

$$\boxed{BV_{CEO} = 65.4\text{V}}$$

7-

Given parameters

$\beta_F = 100,$

$V_A = 50\text{V},$

$BV_{CBO} = 120\text{V}$ and

$n = 4$

We know that $\alpha_F = \dfrac{\beta_F}{\beta_F + 1}$

$$\alpha_F = \frac{100}{100+1}$$

$\alpha_F = 0.99$

Given $I_C - V_{CE}$ characteristic equation

$$I_C = \left(1 + \frac{V_{CE}}{V_A}\right) \frac{M\alpha_F}{1 - M\alpha_F} I_B \ldots\ldots\ldots \text{(1)}$$

Here $M = \dfrac{1}{1 - \left(\dfrac{V_{CB}}{BV_{CBO}}\right)^n}$

Assume $V_{CB} = V_{CE}$, then

$$M = \frac{1}{1-\left(\frac{V_{CE}}{120}\right)^4}$$

$$M = \frac{120^4}{120^4 - \left(V_{CE}\right)^4}$$

Now equation (1) becomes

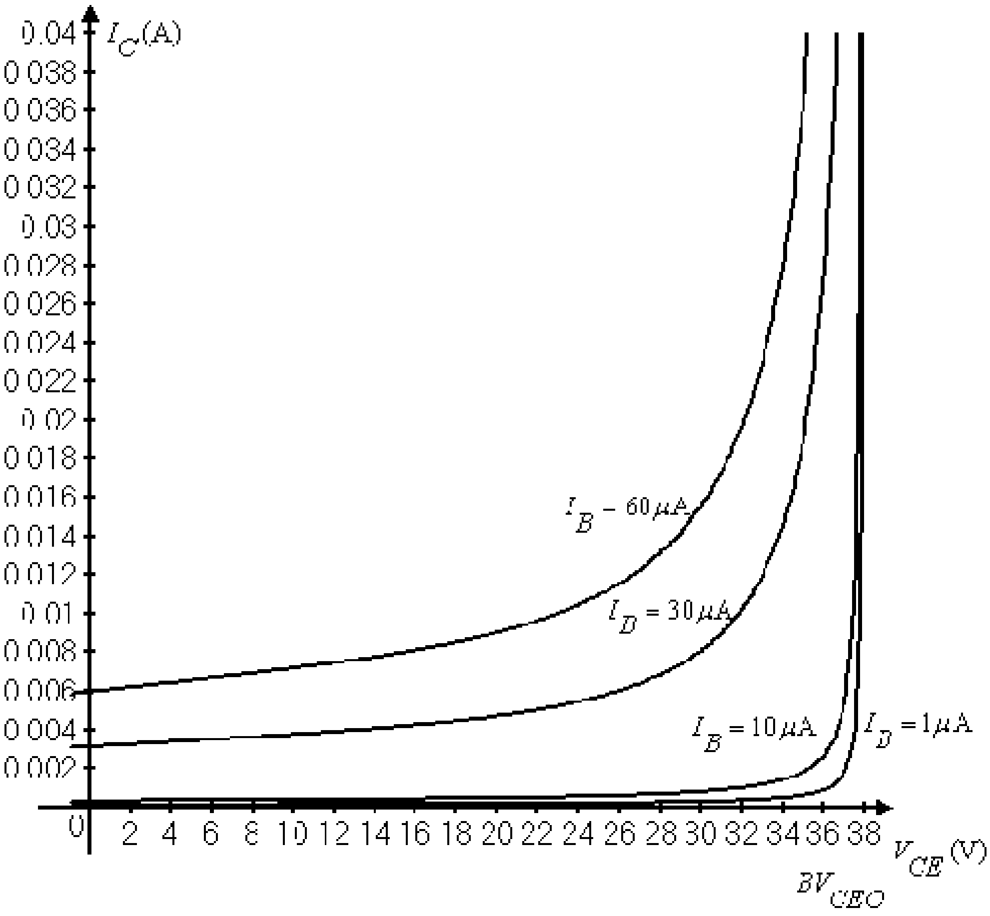
$$I_C = \left(1+\frac{V_{CE}}{50}\right)\left[\frac{\left(\frac{120^4}{120^4-\left(V_{CE}\right)^4}\right)0.99}{1-\left(\frac{120^4}{120^4-\left(V_{CE}\right)^4}\right)0.99}\right]I_B$$

$$I_C = \left(\frac{50+V_{CE}}{50}\right)\left[\frac{120^4 \times 0.99}{120^4-\left(V_{CE}\right)^4-120^4\times 0.99}\right]I_B$$

$$I_C = \left[\frac{4105728\left(50+V_{CE}\right)}{2073600-\left(V_{CE}\right)^4}\right]I_B$$

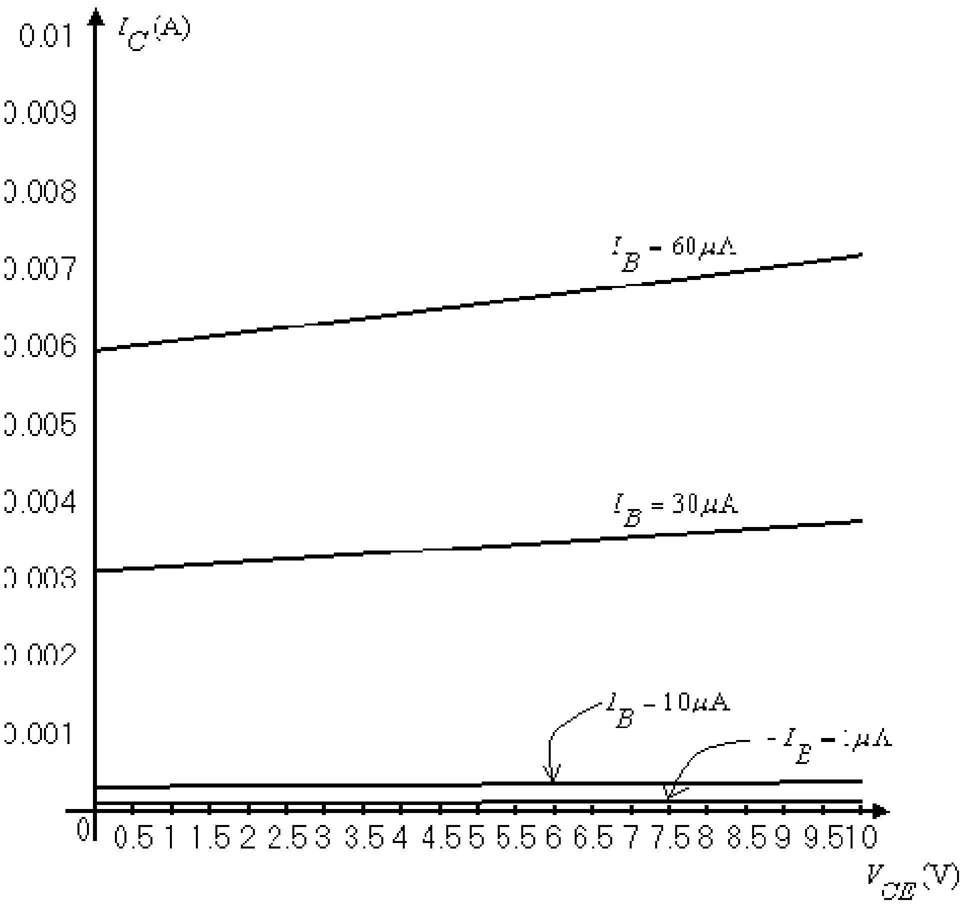
(a)

For different values of I_B we can get $I_C - V_{CE}$ characteristic curve as below


I_C(A)
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
V_{CE}(V)
BV_{CEO}
$I_B = 60\mu$A
$I_B = 30\mu$A
$I_B = 10\mu$A
$I_B = 1\mu$A

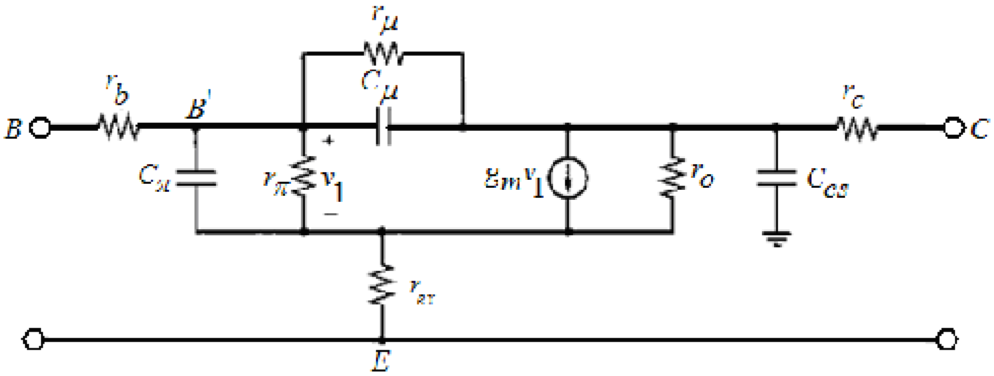
(b)

$I_C - V_{CE}$ characteristic curve for V_{CE} 0 to 10V



8-

Bipolar transistor small-signal equivalent circuit is as below



Given data

$I_C = 0.2\text{mA},\ V_{CB} = 3\text{V},\ V_{CS} = 4\text{V}$

$C_{je0} = 20\text{fF},\ C_{\mu0} = 10\text{fF},\ C_{cs0} = 20\text{fF},\ \beta_0 = 100,\ \tau_F = 15\text{ps},$

$\eta = 10^{-3},\ r_b = 200\Omega,\ r_c = 100\Omega,\ r_{ex} = 4\Omega$ and $r_\mu = 5\beta_0 r_o$

Here assumption is $\psi_0 = 0.55\text{V}$

The collector base capacitance is

$$C_\mu = \frac{C_{\mu0}}{\left(1+\frac{V_{CB}}{\psi_{0C}}\right)^{n_c}} \ldots\ldots\ldots\ldots (1)$$

n_c value varies from 0.2 to 0.5.

Let us assume $n_c = 0.5$

Now equation (1) become

$$C_\mu = \frac{C_{\mu0}}{\sqrt{1+\frac{V_{CB}}{\psi_{0C}}}}$$

$$C_\mu = \frac{10\times10^{-15}}{\sqrt{1+\frac{3}{0.55}}}$$

$$C_\mu = \frac{10\times10^{-15}}{\sqrt{6.454545}}$$

$$C_\mu = 3.936\times10^{-15}$$

$$C_\mu = 3.936\text{fF}$$

Collector substrate capacitance is

$$C_{cs} = \frac{C_{cs0}}{\left(1+\frac{V_{CS}}{\psi_{0s}}\right)^{n_s}} \text{ ……….. (2)}$$

Here $n_s = 0.5$

Now equation (2) becomes

$$C_{cs} = \frac{C_{cs0}}{\sqrt{1+\frac{V_{CS}}{\psi_{0s}}}}$$

$$C_{cs} = \frac{20\times10^{-15}}{\sqrt{1+\frac{4}{0.55}}}$$

$$C_{cs} = \frac{20\times10^{-15}}{2.876}$$

$$C_{cs} = 6.95\times10^{-15}$$

$$C_{cs} = 6.95\text{fF}$$

Transconductance is

$$g_m = \frac{I_C}{V_T}$$

$$g_m = \frac{0.2\times10^{-3}}{26\times10^{-3}}$$

$$g_m = 7.692\times10^{-3}$$

$$g_m = 7.692\text{mV/A}$$

Input resistance is

$$r_\pi = \frac{\beta_o}{g_m}$$

$$r_\pi = \frac{100}{7.692\times10^{-3}}$$

$$r_\pi = 13000.52\Omega$$

$$r_\pi = 13\text{k}\Omega$$

Output resistance is

$$r_o = \frac{V_A}{I_C} = \frac{1}{\eta g_m}$$

$$r_o = \frac{1}{10^{-3}\times7.692\times10^{-3}}$$

$$r_o = 130005.2\Omega$$

$$r_o = 130\text{k}\Omega$$

Collector-base resistance is

$$r_\mu = 5\beta_0 r_o$$

$$r_\mu = 5(100)\left(130\times10^3\right)$$

$$r_\mu = 65\text{M}\Omega$$

Base charge capacitance is

$C_b = \tau_F g_m$

Given $\tau_F = 15\text{pF}$

$C_b = \left(15\times10^{-12}\right)\left(7.692\times10^{-3}\right)$

$C_b = 115.38\times10^{-15}$

$C_b = 115.38\text{ fF}$

Base-emitter capacitor is

$C_\pi = C_b + C_{je}$

We know that $C_{je} \approx 2C_{je0}$

$C_{je} = 2\left(20\times10^{-15}\right)$

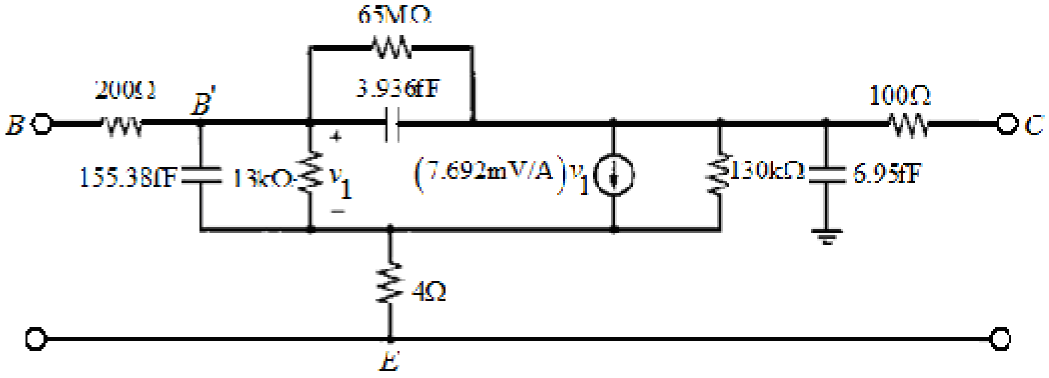
$C_{je} = 40\times10^{-15}$

$C_\pi = 115.38\times10^{-15} + 40\times10^{-15}$

$C_\pi = 155.38\times10^{-15}$

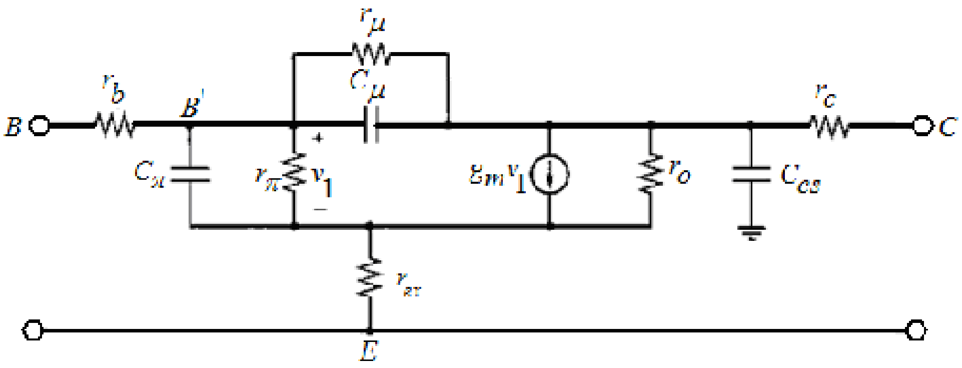
$C_\pi = 155.38\text{fF}$

The equivalent circuit with all parameter values is



9-

Bipolar transistor small-signal equivalent circuit is as below



Given data

$I_C = 1\text{mA},\ V_{CB} = 1\text{V},\ V_{CS} = 2\text{V}$

$C_{je0} = 20\text{fF},\ C_{\mu0} = 10\text{fF},\ C_{cs0} = 20\text{fF},\ \beta_0 = 100,\ \tau_F = 15\text{ps},$

$\eta = 10^{-3},\ r_b = 200\Omega,\ r_c = 100\Omega,\ r_{ex} = 4\Omega$ and $r_\mu = 5\beta_0 r_o$

Here assumption is $\psi_0 = 0.55\text{V}$

The collector base capacitance is

$$C_\mu = \frac{C_{\mu0}}{\left(1+\frac{V_{CB}}{\psi_{0C}}\right)^{n_C}} \ldots\ldots\ldots\ldots (1)$$

n_c value varies from 0.2 to 0.5.

Let us assume $n_c = 0.5$

Now equation (1) become

$$C_\mu = \frac{C_{\mu 0}}{\sqrt{1+\frac{V_{CB}}{\psi_{0C}}}}$$

$$C_\mu = \frac{10\times 10^{-15}}{\sqrt{1+\frac{1}{0.55}}}$$

$$C_\mu = \frac{10\times 10^{-15}}{\sqrt{2.81818}}$$

$$C_\mu = 5.96\times 10^{-15}$$

$$C_\mu = 5.96\text{fF}$$

Collector substrate capacitance is

$$C_{cs} = \frac{C_{cs0}}{\left(1+\frac{V_{CS}}{\psi_{0s}}\right)^{n_S}} \text{ ……….. (2)}$$

Here $n_s = 0.5$

Now equation (2) becomes

$$C_{cs} = \frac{C_{cs0}}{\sqrt{1+\frac{V_{CS}}{\psi_{0s}}}}$$

$$C_{cs} = \frac{20\times10^{-15}}{\sqrt{1+\frac{2}{0.55}}}$$

$$C_{cs} = \frac{20\times10^{-15}}{2.1532}$$

$$C_{cs} = 9.288\times10^{-15}$$

$$C_{cs} = 9.288\text{fF}$$

Transconductance is

$$g_m = \frac{I_C}{V_T}$$

$$g_m = \frac{1\times10^{-3}}{26\times10^{-3}}$$

$$g_m = 38.462\times10^{-3}$$

$$g_m = 38.462\text{mV/A}$$

Input resistance is

$$r_\pi = \frac{\beta_o}{g_m}$$