1.

2.35

(a) $I_C = \frac{1}{r_o}(V_{CE} + V_A) \Rightarrow r_o = \frac{(V_{CE} + V_A)}{I_C}$

(i) $r_o = \frac{2+120}{1.2} = 101.67\,\text{k}\Omega$

(ii) $g_o = \frac{1}{r_o} = \frac{1}{101.67} = 0.00984\,(\text{k}\Omega)^{-1}$

$= 9.84 \times 10^{-6}\,(\Omega)^{-1}$

(iii) $I_C = \frac{4+120}{101.667} = 1.22\,\text{mA}$

(b)

(i) $r_o = \frac{V_{CE} + V_A}{I_C} = \frac{2+160}{0.25} = 648\,\text{k}\Omega$

(ii) $g_o = \frac{1}{r_o} = \frac{1}{648} = 0.00154\,(\text{k}\Omega)^{-1}$

$= 1.54 \times 10^{-6}\,(\Omega)^{-1}$

(iii) $I_C = \frac{4+160}{648} = 0.253\,\text{mA}$

2.

$$x_{dB} = \left\{ \frac{2\in_s (V_{bi}+V_{CB})}{e} \left[\frac{N_C}{N_B} \cdot \frac{1}{(N_B+N_C)} \right] \right\}^{1/2}$$

$$= \left\{ \frac{2(11.7)(8.85\times10^{-14})(V_{bi}+V_{CB})}{1.6\times10^{-19}} \right.$$

$$\left. \times \left[\frac{2\times10^{15}}{2\times10^{16}} \cdot \frac{1}{(2\times10^{15}+2\times10^{16})} \right] \right\}^{1/2}$$

$$= \{(5.8832\times10^{-11})(V_{bi}+V_{CB})\}^{1/2}$$

Now

$$V_{bi} = V_t \ln\left(\frac{N_B N_C}{n_i^2} \right)$$

$$= (0.0259)\ln\left[\frac{(2\times10^{15})(2\times10^{16})}{(1.5\times10^{10})^2} \right]$$

$$= 0.6709\ \text{V}$$

(i) For $V_{CB} = 4\ \text{V}$, $x_{dB} = 0.1658\ \mu\text{m}$

(ii) For $V_{CB} = 8\ \text{V}$, $x_{dB} = 0.2259\ \mu\text{m}$

(iii) For $V_{CB} = 12\ \text{V}$, $x_{dB} = 0.2730\ \mu\text{m}$

Neglecting the B-E space charge width,

(i) For $V_{CB} = 4\ \text{V}$,

$$x_B = 0.85 - 0.1658 = 0.6842\ \mu\text{m}$$

(ii) For $V_{CB} = 8\ \text{V}$,

$$x_B = 0.85 - 0.2259 = 0.6241\ \mu\text{m}$$

(iii) For $V_{CB} = 12\ \text{V}$,

$$x_B = 0.85 - 0.2730 = 0.5770\ \mu\text{m}$$

Now

$$J_C = \frac{eD_B n_{B0}}{x_B} \exp\left(\frac{V_{BE}}{V_t} \right)$$

where

$$n_{B0} = \frac{n_i^2}{N_B} = \frac{(1.5\times10^{10})^2}{2\times10^{16}}$$

$$= 1.125\times10^4\ \text{cm}^{-3}$$

so

$$J_C = \frac{(1.6\times10^{-19})(25)(1.125\times10^4)}{x_B} \exp\left(\frac{0.650}{0.0259} \right)$$

$$= \frac{3.5686\times10^{-3}}{x_B}\ \text{A/cm}^2$$

(i)For $V_{CB} = 4\ \text{V}$, $J_C = 52.16\ \text{A/cm}^2$

(ii)For $V_{CB} = 8\ \text{V}$, $J_C = 57.18\ \text{A/cm}^2$

(iii)For $V_{CB} = 12\ \text{V}$, $J_C = 61.85\ \text{A/cm}^2$

(b) $$\frac{\Delta J_C}{\Delta V_{CE}} = \frac{J_C}{V_{CE}+V_A}$$

$$\frac{61.85-52.16}{12-4} = \frac{52.16}{4+0.650+V_A}$$

$$\Rightarrow V_A = 38.4\ \text{V}$$

3.

(a)

$$x_{dB} = \left\{ \frac{2 \in_s (V_{bi} + V_{BC})}{e} \left[\frac{N_C}{N_B} \cdot \frac{1}{(N_B + N_C)} \right] \right\}^{1/2}$$

$$= \left\{ \frac{2(11.7)(8.85 \times 10^{-14})(V_{bi} + V_{BC})}{1.6 \times 10^{-19}} \right.$$

$$\left. \times \left[\frac{10^{15}}{10^{16}} \cdot \frac{1}{(10^{15} + 10^{16})} \right] \right\}^{1/2}$$

$$= \left\{ (1.1766 \times 10^{-10})(V_{bi} + V_{BC}) \right\}^{1/2}$$

Now

$$V_{bi} = V_t \ln\left(\frac{N_B N_C}{n_i^2} \right)$$

$$= (0.0259) \ln\left[\frac{(10^{15})(10^{16})}{(1.5 \times 10^{10})^2} \right]$$

$$= 0.6350 \text{ V}$$

For $V_{BC} = 1 \text{ V}$, $x_{dB} = 0.1387\ \mu\text{m}$

For $V_{BC} = 5 \text{ V}$, $x_{dB} = 0.2575\ \mu\text{m}$

Then $\Delta x_{dB} = 0.2575 - 0.1387 = 0.1188\ \mu\text{m}$

(b) $I_C = \dfrac{e D_B p_{B0} A_{BE}}{x_B} \exp\left(\dfrac{V_{EB}}{V_t} \right)$

We find

$$p_{B0} = \frac{n_i^2}{N_B} = \frac{(1.5 \times 10^{10})^2}{10^{16}}$$

$$= 2.25 \times 10^4 \text{ cm}^{-3}$$

Then

$$I_C = \frac{(1.6 \times 10^{-19})(10)(2.25 \times 10^4)(10^{-4})}{x_B}$$

$$\times \exp\left(\frac{0.625}{0.0259} \right)$$

$$= \frac{1.0874 \times 10^{-7}}{x_B} \text{ A}$$

For $V_{BC} = 1 \text{ V}$, $I_C = \dfrac{1.0874 \times 10^{-7}}{(0.70 - 0.1387) \times 10^{-4}}$

$$= 1.937 \times 10^{-3} \text{ A} = 1.937 \text{ mA}$$

For $V_{BC} = 5 \text{ V}$, $I_C = \dfrac{1.0874 \times 10^{-7}}{(0.70 - 0.2575) \times 10^{-4}}$

$$= 2.456 \times 10^{-3} \text{ A} = 2.456 \text{ mA}$$

Then

$$\Delta I_C = 2.456 - 1.937 = 0.519 \text{ mA}$$

(c) $\dfrac{\Delta I_C}{\Delta V_{BC}} = \dfrac{I_C}{V_{EC} + V_A}$

$$\frac{0.519 \times 10^{-3}}{5 - 1} = \frac{1.937 \times 10^{-3}}{1 + 0.625 + V_A}$$

$$V_A = 13.3 \text{ V}$$

(d) $r_o = \dfrac{V_{EC} + V_A}{I_C} = \dfrac{1.625 + 13.3}{1.937 \times 10^{-3}}$

$$= 7.705 \times 10^3\ \Omega = 7.705 \text{ k}\Omega$$

4.

(a) $V_{bi} = \phi_{B0} - \phi_n$

$$\phi_n = V_t \ln\left(\frac{N_c}{N_d}\right)$$

$$= (0.0259)\ln\left(\frac{2.8\times10^{19}}{5\times10^{15}}\right)$$

$$=0.2235 \text{ V}$$

$$V_{bi} = 0.65 - 0.2235 = 0.4265 \text{ V}$$

(b) $\phi_n = (0.0259)\ln\left(\frac{2.8\times10^{19}}{10^{16}}\right)$

$$= 0.2056 \text{ V}$$

$$V_{bi} = 0.65 - 0.2056 = 0.4444 \text{ V}$$

V_{bi} increases, ϕ_{B0} remains constant

(c) $\phi_n = (0.0259)\ln\left(\frac{2.8\times10^{19}}{10^{15}}\right)$

$$= 0.2652 \text{ V}$$

$$V_{bi} = 0.65 - 0.2652 = 0.3848 \text{ V}$$

V_{bi} decreases, ϕ_{B0} remains constant

5.

(a) $\phi_{B0} \cong 0.63\text{ V}$

$$J_{sT} = (120)(300)^2 \exp\left(\frac{-0.63}{0.0259}\right)$$

$$= 2.948\times10^{-4}\text{ A/cm}^2$$

$$I_{sT} = (10^{-4})(2.948\times10^{-4}) = 2.948$$

(i) $V_a = V_t \ln\left(\dfrac{I}{I_{sT}}\right)$

$$= (0.0259)\ln\left(\frac{10\times10^{-6}}{2.948\times10^{-8}}\right)$$

$$= 0.151\text{ V}$$

(ii) $V_a = (0.0259)\ln\left(\dfrac{100\times10^{-6}}{2.948\times10^{-8}}\right)$

$$= 0.211\text{ V}$$

(iii) $V_a = (0.0259)\ln\left(\dfrac{10^{-3}}{2.948\times10^{-8}}\right)$

$$= 0.270\text{ V}$$

(b) $kT = (0.0259)\left(\dfrac{350}{300}\right) = 0.030217\text{ eV}$

$$I_{sT} = (10^{-4})(120)(350)^2 \exp\left(\frac{-0.63}{0.030217}\right)$$

$$= 1.296\times10^{-6}\text{ A}$$

(i) $I = I_{sT}\left[\exp\left(\dfrac{V_a}{V_t}\right) - 1\right]$

$$V_a = (0.030217)\ln\left[\frac{10\times10^{-6}}{1.296\times10^{-6}} + 1\right]$$

$$= 0.0654\text{ V}$$

(ii) $V_a = (0.030217)\ln\left[\dfrac{100\times10^{-6}}{1.296\times10^{-6}} + 1\right]$

$$= 0.1317\text{ V}$$

(iii) $V_a \cong (0.030217)\ln\left(\dfrac{10^{-3}}{1.296\times10^{-6}}\right)$

$$= 0.201\text{ V}$$

6.

For the pn junction,

$$I_s = (8\times10^{-4})(8\times10^{-13}) = 6.4\times10^{-16}\ \text{A}$$

(a) $$V_a = (0.0259)\ln\left(\frac{150\times10^{-6}}{6.4\times10^{-16}}\right)$$

$$= 0.678\ \text{V}$$

(b) $$V_a = (0.0259)\ln\left(\frac{700\times10^{-6}}{6.4\times10^{-16}}\right)$$

$$= 0.718\ \text{V}$$

(c) $$V_a = (0.0259)\ln\left(\frac{1.2\times10^{-3}}{6.4\times10^{-16}}\right)$$

$$= 0.732\ \text{V}$$

For the Schottky junction,

$$I_{sT} = (8\times10^{-4})(6\times10^{-9}) = 4.8\times10^{-12}\ \text{A}$$

(a) $$V_a = (0.0259)\ln\left(\frac{150\times10^{-6}}{4.8\times10^{-12}}\right)$$

$$= 0.447\ \text{V}$$

(b) $$V_a = (0.0259)\ln\left(\frac{700\times10^{-6}}{4.8\times10^{-12}}\right)$$

$$= 0.487\ \text{V}$$

(c) $$V_a = (0.0259)\ln\left(\frac{1.2\times10^{-3}}{4.8\times10^{-12}}\right)$$

$$= 0.501\ \text{V}$$

7.

(a) $R = \frac{R_c}{A} = \frac{5\times10^{-5}}{10^{-5}} = 5\Omega$

(i) $V = IR = (1)(5) = 5\,\text{mV}$

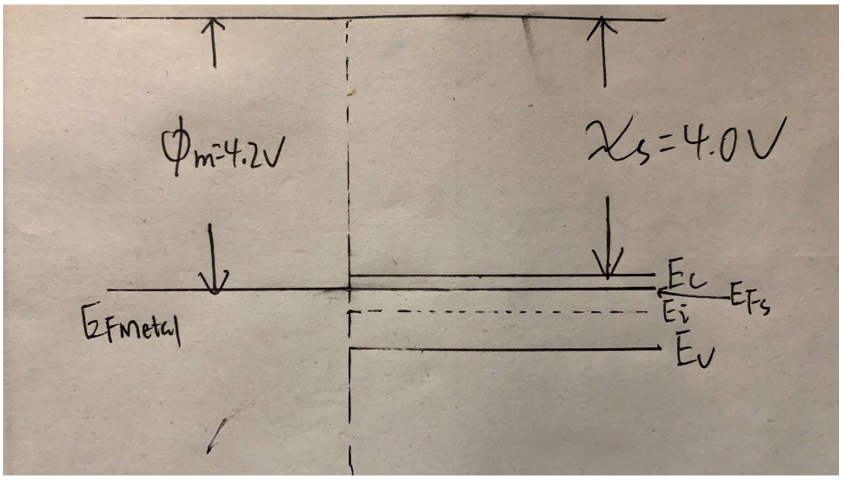
(ii) $V = IR = (0.1)(5) = 0.5\,\text{mV}$

(b) $R = \frac{5\times10^{-5}}{10^{-6}} = 50\ \Omega$

(i) $V = IR = (1)(50) = 50\,\text{mV}$

(ii) $V = IR = (0.1)(50) = 5\,\text{mV}$

8.



(b) We need $\phi_n = \phi_m - \chi = 4.2 - 4.0 = 0.20\,\text{V}$

And

$$\phi_n = V_t \ln\left(\frac{N_c}{N_d}\right)$$

or

$$0.20 = (0.0259)\ln\left(\frac{2.8\times10^{19}}{N_d}\right)$$

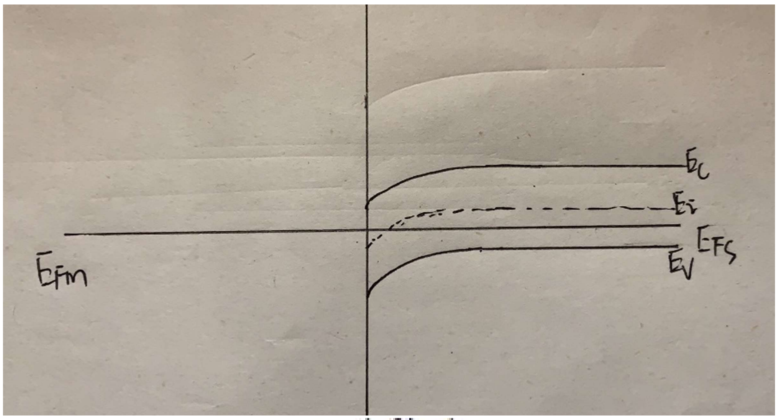
which yields

$$N_d = 1.24\times10^{16}\ \text{cm}^{-3}$$

(c)

Barrier height = 0.20 V

9.



(b) $\phi_{BO} = \phi_p = V_t \ln\left(\frac{N_v}{N_a}\right)$

$$= (0.0259)\ln\left(\frac{1.04\times10^{19}}{5\times10^{16}}\right)$$

or

$$\phi_{BO} = 0.138 \text{ V}$$