12.9 A uniformly doped silicon npn bipolar transistor at $T = 300$ K is biased in the forward-active mode. The doping concentrations are $N_E = 8 \times 10^{17}$ cm^{-3}, $N_B = 2 \times 10^{16}$ cm^{-3}, and $N_C = 10^{15}$ cm^{-3}. (*a*) Determine the thermal-equilibrium values p_{E0}, n_{B0}, and p_{C0}. (*b*) For $V_{BE} = 0.640$ V, calculate the values of n_B at $x = 0$ and p_E at $x' = 0$.

Per Table B.4, $n_i = 1.5 \times 10^{10}$ cm^{-3} @ 300K for Si

a) (4.43) $n_o p_o = n_i^2$

Assume $n_o = N_E$ for emitter

$$p_{E0} = \frac{(1.5 \times 10^{10})^2}{8 \times 10^{17}} \Rightarrow \underline{\underline{p_{E0} = 281.25 \text{ cm}^{-3}}}$$

Assume $p_o = N_B$ for base

$$n_{B0} = \frac{(1.5 \times 10^{10})^2}{2 \times 10^{16}} \Rightarrow \underline{\underline{n_{B0} = 1.125 \times 10^{4} \text{ cm}^{-3}}}$$

Assume $n_o = N_c$ for collector

$$p_{C0} = \frac{(1.5 \times 10^{10})^2}{10^{15}} \Rightarrow \underline{\underline{p_{C0} = 2.25 \times 10^{5} \text{ cm}^{-3}}}$$

b) (12.13a) $\delta n_B(0) = n_B(0) = n_{B0}\left[e^{V_{BE}/V_t} - 1\right]$

$$(7.10)\quad V_t = \frac{k_B T}{e} = \frac{8.617333 \times 10^{-5} \text{ eV/K } (300\text{K})}{e} = 0.025852 \text{ V}$$

$$n_B(0) = 1.125 \times 10^{-4}\left[e^{\frac{0.64}{0.025852}} - 1\right] \Rightarrow \underline{\underline{n_B(0) = 6.3486 \times 10^{14} \text{ cm}^{-3}}}$$

(12.20a) $\delta p_E(0) = p_E(0) = p_{E0}\left[e^{V_{BE}/V_t} - 1\right]$

$$p_E(0) = 281.25\left[e^{\frac{0.64}{0.025852}} - 1\right] \Rightarrow \underline{\underline{p_E(0) = 1.5872 \times 10^{13} \text{ cm}^{-3}}}$$