6.30 An n-type silicon semiconductor, doped at $N_d = 4 \times 10^{16}$ cm^{-3}, is steadily illuminated such that $g' = 2 \times 10^{21}$ cm^{-3} s^{-1}. Assume $\tau_{n0} = 10^{-6}$ s and $\tau_{p0} = 5 \times 10^{-7}$ s. (*a*) Determine the thermal-equilibrium value of $E_F - E_{Fi}$. (*b*) Calculate the quasi-Fermi levels for electrons and holes with respect to E_{Fi}. (*c*) What is the difference (in eV) between E_{Fn} and E_F ?

- First, find the electron and hole concentrations at thermal equilibrium. In part b), also find the excess charge carrier concentration.

Assume 300K. From Table B.4, $n_i = 1.5 \times 10^{10}$ #/cm^3

Since $N_d >> n_i$, $\underline{\underline{n_o \simeq N_d = 4 \times 10^{16} \text{ \#/cm}^3}}$

Per (4.43), $p_o = \frac{n_i^2}{n_o} = \frac{(1.5 \times 10^{10})^2}{4 \times 10^{16}} \Rightarrow \underline{\underline{p_o = 5625 \text{ \#/cm}^3}}$

a) Per (6.84) $n_o = n_i e^{\frac{E_F - E_{Fi}}{k_B T}}$

$\hookrightarrow E_F - E_{Fi} = k_B T \ln\left(\frac{n_o}{n_i}\right)$

$= 8.617333 \times 10^{-5} \frac{eV}{K} (300K) \ln\left(\frac{4 \times 10^{16}}{1.5 \times 10^{10}}\right)$

$\underline{\underline{E_F - E_{Fi} = 0.382515 \text{ eV}}}$

b) Looking at (6.85a) + (6.85b), we need $\delta n = \delta p$. At steady-state w/ no electric field and uniform illumination, (6.56) becomes

$$D_p \underbrace{\frac{\partial^2(\delta p)}{\partial x^2}}_{\to 0} - \mu_p \underbrace{E \frac{\partial(\delta p)}{\partial x}}_{\to 0} + g' - \frac{\delta p}{\tau_{p0}} = \underbrace{\frac{\partial(\delta p)}{\partial t}}_{\to 0}$$

$\hookrightarrow \delta p = \tau_{p0} g' = 2 \times 10^{21} (5 \times 10^{-7}) = 1 \times 10^{15}$ #/cm^3

b) cont.

(6.85a) $n_0 + \delta n = n_i e^{\frac{E_{Fn} - E_{Fi}}{k_B T}}$

$E_{Fn} - E_{Fi} = k_B T \ln\left(\frac{n_0 + \delta n}{n_i}\right)$

$= 8.617333 \times 10^{-5} (300) \ln\left(\frac{4 \times 10^{16} + 1 \times 10^{15}}{1.5 \times 10^{10}}\right)$

$\underline{\underline{E_{Fn} - E_{Fi} = 0.383153 \, eV}}$

(6.85b) $p_0 + \delta p = n_i e^{\frac{E_{Fi} - E_{Fp}}{k_B T}}$

$E_{Fi} - E_{Fp} = k_B T \ln\left(\frac{p_0 + \delta p}{n_i}\right)$

$= 8.617333 \times 10^{-5} (300) \ln\left(\frac{5625 + 10^{15}}{1.5 \times 10^{10}}\right)$

$\underline{\underline{E_{Fi} - E_{Fp} = 0.28715 \, eV}}$

c) $(E_{Fn} - E_{Fi}) - (E_F - E_{Fi}) = 0.383153 - 0.382515$

$\underline{\underline{E_{Fn} - E_F = 0.000638 \, eV = 0.638 \, meV}}$