6.1 Consider silicon at $T = 300$ K that is doped with donor impurity atoms to a concentration of $N_d = 5 \times 10^{15}$ cm^{-3}. The excess carrier lifetime is 2×10^{-7}s. (*a*) Determine the thermal equilibrium recombination rate of holes. (*b*) Excess carriers are generated such that $\delta n = \delta p = 10^{14}$ cm^{-3}. What is the recombination rate of holes for this condition?

- First, find the electron and hole concentration at thermal equilibrium.

Table B.4 gives an intrinsic charge concentration $n_i = 1.5 \times 10^{10}$ #/cm^3 at 300 K for silicon. Assume $N_a = 0$.

This n_i is negligible compared to N_d $\Rightarrow$ $\mathbf{n_0 \approx N_d = 5 \times 10^{15}}$ **#/cm^3.**

Per (4.43), $n_0 p_0 = n_i^2$. So, $p_0 = n_i^2 / n_0 = (1.5 \times 10^{10})^2 / 5 \times 10^{15}$ $\Rightarrow$ $\mathbf{p_0 = 4.5 \times 10^4}$ **#/cm^3.**

a) The thermal equilibrium recombination rate is

$$R_{p0} = p_0 / \tau_{p0} = 4.5 \times 10^4 / 2 \times 10^{-7} \quad \Rightarrow \quad \mathbf{R_{p0} = 2.25 \times 10^{11}} \text{ #/cm}^3\text{-s.}$$

b) The excess carrier recombination rate (6.13) is

$$R_p' = \delta p(t) / \tau_{p0} = 10^{14} / 2 \times 10^{-7} \quad \Rightarrow \quad \mathbf{R_p' = 5 \times 10^{20}} \text{ #/cm}^3\text{-s.}$$

The overall hole recombination rate is

$$R_p' + R_{p0} = 5 \times 10^{20} + 2.25 \times 10^{11} \quad \Rightarrow \quad \mathbf{R_p' + R_{p0} \approx R_p' \approx 5 \times 10^{20}} \text{ #/cm}^3\text{-s.}$$