4.39 A silicon semiconductor material at $T = 300$ K is doped with arsenic atoms to a concentration of 2×10^{15} cm^{-3} and with boron atoms to a concentration of 1.2×10^{15} cm^{-3}. (*a*) Is the material n type or p type? (*b*) Determine n_0 and p_0. (*c*) Additional boron atoms are to be added such that the hole concentration is 4×10^{15} cm^{-3}. What concentration of boron atoms must be added and what is the new value of n_0?

a) Per Table 4.3, arsenic is a donor while boron is an acceptor. Since, $N_{As} > N_B$, the material is n-type.

b) From Table B.4, $n_i = 1.5 \times 10^{10} \frac{\#}{cm^3}$.

Assuming complete ionization along w/ $N_d > N_a$, we use (4.60)

$$n_0 = \frac{N_d - N_a}{2} + \sqrt{\left(\frac{N_d - N_a}{2}\right)^2 + n_i^2}$$

$$= \frac{(2-1.2)\times 10^{15}}{2} + \sqrt{\left(\frac{0.8\times 10^{15}}{2}\right)^2 + (1.5\times 10^{10})^2}$$

$$n_0 = 8 \times 10^{14} \frac{\#}{cm^3}$$

(4.43) $n_0 p_0 = n_i^2 \Rightarrow p_0 = \frac{(1.5\times 10^{10})^2}{8\times 10^{14}} \Rightarrow p_0 = 2.8125 \times 10^5 \frac{\#}{cm^3}$

c) Call the additional boron ΔN_a and assume complete ionization. Per (4.62)

$$p_0 = \frac{N_a - N_d}{2} + \sqrt{\left(\frac{N_a - N_d}{2}\right)^2 + n_i^2} \cong N_a - N_d$$

$$4\times 10^{15} = (1.2\times 10^{15} + \Delta N_a) - 2\times 10^{15}$$

$$\Delta N_a = 4.8 \times 10^{15} \frac{\#}{cm^3}$$

(4.43) $n_0 = \frac{(1.5\times 10^{10})^2}{(4.8+1.2)\times 10^{15}} \Rightarrow n_0 = 3.75 \times 10^4 \frac{\#}{cm^3}$