5.7 A silicon crystal having a cross-sectional area of 0.001 cm^2 and a length of 10^{-3} cm is connected at its ends to a 10-V battery. At $T = 300$ K, we want a current of 100 mA in the silicon. Calculate (*a*) the required resistance R, (*b*) the required conductivity, (*c*) the density of donor atoms to be added to achieve this conductivity, and (*d*) the concentration of acceptor atoms to be added to form a compensated p-type material with the conductivity given from part (*b*) if the initial concentration of donor atoms is $N_d = 10^{15}\ cm^{-3}$.

a) By Ohm's Law, $R = V/I = 10/100\times10^{-3}$ $\Rightarrow$ $\underline{R = 100\ \Omega}$.

b) Per (5.22b), $R = L/\sigma A$. Solving for the conductivity, we get

$$\sigma = L/RA = 10^{-3}\text{ cm} / [100\,(0.001\text{ cm}^2)] \quad \Rightarrow \quad \underline{\sigma = 0.01\text{ S/cm} = 1\text{ S/m}}.$$

c) Per (5.23), $\sigma = e\,(\mu_n n + \mu_p p)$.

Assume $N_a = 0$. Table B.4 gives an intrinsic charge concentration $n_i = 1.5\times10^{10}$ #/cm^3 at 300 K for silicon. This is negligible compared to typical N_d. So, $n \approx N_d$. This also implies that p is negligible compared to n. This gives $\sigma \approx e\,\mu_n N_d$.

Going to Table 5.2, we will let $\mu_n = 1350\ cm^2/V\text{-}s = 0.135\ m^2/V\text{-}s$ and solve for the donor concentration

$$N_d \approx \sigma / e\,\mu_n = 1/[1.602176634\times10^{-19}\,(0.135)]$$

$$\Rightarrow \underline{N_d = 4.62334\times10^{19}\ \#/m^3 = 4.62334\times10^{13}\ \#/m^3}.$$

d) Per (5.23), $\sigma = e(\mu_n n + \mu_p p)$.

Assume we have all p-type carriers. This implies that n is negligible compared to p [see (4.43), $n_0 p_0 = n_i^2$]. This gives $\sigma \approx e\,\mu_p p$.

Going to Table 5.2, we will let $\mu_p = 480\ cm^2/V\text{-}s = 0.048\ m^2/V\text{-}s$ and let $p = N_a - N_d$ for our compensated p-type semiconductor. This gives

$$\sigma = 1\text{ S/m} \approx e\,\mu_p p = (1.602176634\times10^{-19})\,0.048\,(N_a - 10^{21}).$$

Solving for the acceptor concentration

$$N_a - 10^{21} \approx \sigma / e\,\mu_p = 1/[1.602176634\times10^{-19}\,(0.048)] = 1.30031\times10^{20}$$

$$N_a \approx 1.30031\times10^{20} + 10^{21} \quad \Rightarrow \underline{N_a = 1.13003\times10^{21}\ \#/m^3 = 1.13003\times10^{15}\ \#/m^3}.$$

Note: Looking at Figure 5.3, the assumed mobility values from Table 5.2 correspond to the mobility values when N_a and N_d are smaller than ~ 2×10^{15} #/cm^3. From the results in parts c) and d), the Table 5.2 values are accurate.