5.23 Consider three samples of silicon at $T = 300$ K. The n-type sample is doped with arsenic atoms to a concentration of $N_d = 5 \times 10^{16}$ cm^{-3}. The p-type sample is doped with boron atoms to a concentration of $N_a = 2 \times 10^{16}$ cm^{-3}. The compensated sample is doped with both the donors and acceptors described in the n-type and p-type samples. (*a*) Find the equilibrium electron and hole concentrations in each sample, (*b*) determine the majority carrier mobility in each sample, (*c*) calculate the conductivity of each sample, (*d*) and determine the electric field required in each sample to induce a drift current density of $J = 120$ A/cm^2.

- Changed so that $N_d = 6 \times 10^{16}$ #/cm^3 and $N_a = 3 \times 10^{16}$ #/cm^3.

a) From Table B.4, the intrinsic charge concentration, $n_i \approx 1.5 \times 10^{10}$ #/cm^3, is negligible compared to the doped samples.

- ***n*-type sample**: $n_0 \approx N_d$ ⇒ $n_0 = 6 \times 10^{16}$ #/cm^3

  Use (4.43) to get $p_0 = n_i^2 / n_0 = (1.5 \times 10^{10})^2 / 6 \times 10^{16}$ ⇒ $p_0 = 3{,}750$ #/cm^3

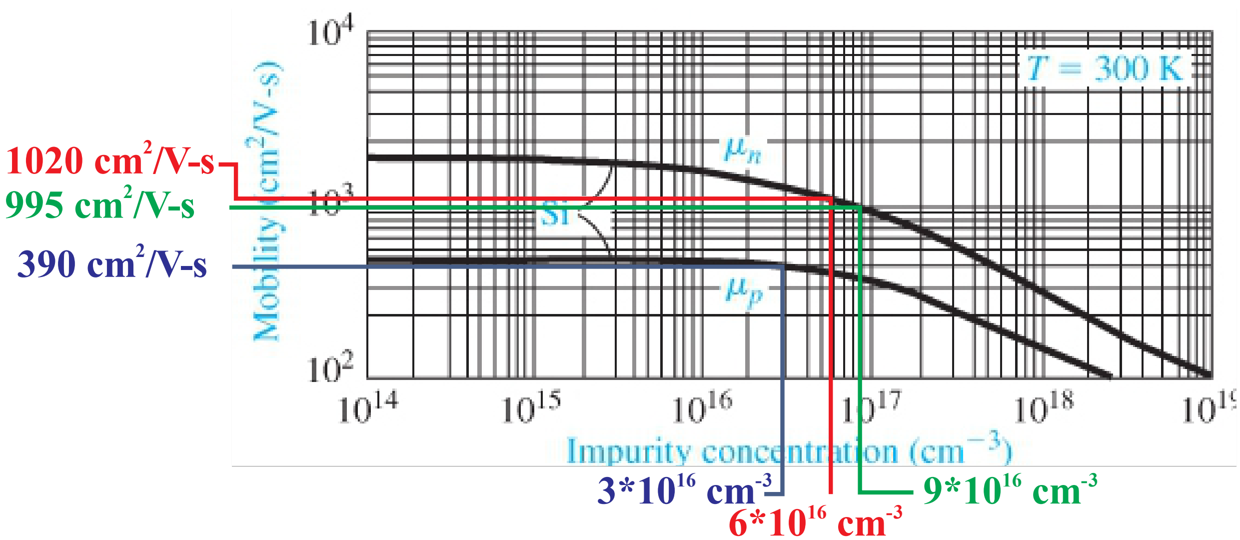
- ***p*-type sample**: $p_0 \approx N_a$ ⇒ $p_0 = 3 \times 10^{16}$ #/cm^3

  Use (4.43) to get $n_0 = n_i^2 / p_0 = (1.5 \times 10^{10})^2 / 3 \times 10^{16}$ ⇒ $n_0 = 7{,}500$ #/cm^3

- **compensated sample**: $n_0 \approx N_d - N_a = (6-3) \times 10^{16}$ #/cm^3 ⇒ $n_0 = 3 \times 10^{16}$ #/cm^3

  Use (4.43) to get $p_0 = n_i^2 / n_0 = (1.5 \times 10^{10})^2 / 3 \times 10^{16}$ ⇒ $p_0 = 7{,}500$ #/cm^3

b) Use Figure 5.3 (middle graph for silicon) to get the majority carrier mobilities.



- ***n*-type sample**: With $N_i \approx N_d = 6 \times 10^{16}$ #/cm^3 ⇒ $\mu_n \approx 1020$ cm^2/V-s
- ***p*-type sample**: With $N_i \approx N_a = 3 \times 10^{16}$ #/cm^3 ⇒ $\mu_p \approx 390$ cm^2/V-s
- **compensated sample**: With $N_i \approx N_d + N_a = 9 \times 10^{16}$ #/cm^3 ⇒ $\mu_n \approx 995$ cm^2/V-s

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

- ***n*-type sample**: $\sigma \simeq e\mu_n N_d = (1.6021766\times10^{-19})1020(6\times10^{16})$ ⇒ ***σ* ≈ 9.805 S/cm**
- ***p*-type sample**: $\sigma \simeq e\mu_p N_a = (1.6021766\times10^{-19})390(3\times10^{16})$ ⇒ ***σ* ≈ 1.875 S/cm**
- **compensated sample**: $\sigma \simeq e\mu_n N_d = (1.6021766\times10^{-19})995(3\times10^{16})$ ⇒ ***σ* ≈ 4.78 S/cm**

d) Per (5.19), $J = \sigma E \Rightarrow E = J/\sigma$.

- ***n*-type sample**: $E = 120/9.805$ ⇒ ***E* ≈ 12.24 V/cm**
- ***p*-type sample**: $E = 120/1.875$ ⇒ ***E* ≈ 64.0 V/cm**
- **compensated sample**: $E = 120/4.78$ ⇒ ***E* ≈ 25.1 V/cm**