1. It is found that Si at $T = 300$ K has the intrinsic concentration $n_i = 1.5 \times 10^{10}$ per cm$^3$. If the bandgap voltage is $V_G = 1.11$ V, show that the constant $n_0$ in the equation

$$n_i = n_0 \left( \frac{T}{300} \right)^{3/2} \exp \left( -\frac{V_G}{2V_T} \right)$$

has the value $n_0 = 3.04 \times 10^{25}$.

2. Copper has two valence electrons per atom, an atomic weight of $63.546$ g/mol, a density of $8230$ kg/m$^3$, and a conductivity of $5.8 \times 10^7$ S/m. (a) If all valence electrons are free, show that the concentration of free electrons is $n = 1.56 \times 10^{29}$ electrons per m$^3$. (b) Show that the electron mobility in copper is $\mu_e = 2.32 \times 10^{-3}$ m$^2$ V$^{-1}$ s$^{-1}$.

3. Show that the diameter of 1 ft of copper wire required to obtain a resistance of 5 $\Omega$ is $d = 1.44 \times 10^{-3}$ in.

4. Let $y = f(x)$. The percentage fractional change in $y$ per change in $x$ is defined by

$$\frac{1}{y} \times \frac{dy}{dx} \times 100\%$$

The intrinsic concentration of silicon is given by

$$n_i = n_0 \left( \frac{T}{300} \right)^{3/2} \exp \left( -\frac{V_G}{2V_T} \right)$$

If $V_G = 1.11$ V and is assumed to be independent of temperature and $V_T = kT/q$, show that the fractional percentage change in the intrinsic concentration for silicon at $T = 300$ K is

$$\left( \frac{3}{2T} + \frac{V_G}{2TV_T} \right) \times 100\% = 7.64\% \text{ per } ^\circ\text{C}$$

5. Let a rod of semiconductor material have a length $\Delta \ell$, a cross-section area $S$, an intrinsic concentration $n_i$, an electron mobility $\mu_e$, and a hole mobility $\mu_h$. Show that the resistance of the rod can be written as the parallel combination of two resistors $R_e$ and $R_h$ given by

$$R_e = \frac{\Delta \ell}{n_i \mu_e q S} \quad R_h = \frac{\Delta \ell}{n_i \mu_h q S}$$

6. A rod of intrinsic silicon is 5 mm long and has a diameter of 1.5 mm. At room temperature, the intrinsic concentration in the silicon is $n_i = 1.5 \times 10^{16}$ per m$^3$. The electron and hole mobilities are $\mu_e = 0.13$ m$^2$ V$^{-1}$ s$^{-1}$ and $\mu_h = 0.05$ m$^2$ V$^{-1}$ s$^{-1}$. Use the results of problem 5 to show that $R_e = 9.06$ M$\Omega$, $R_h = 23.6$ M$\Omega$, and $R = R_e || R_h = 6.54$ M$\Omega$.

7. In the silicon rod of problem 6, the number of silicon atoms per m$^3$ is $5 \times 10^{28}$. An acceptor impurity is added to the silicon in the rate of one donor atom per $10^8$ atoms of silicon. Show that the new resistance of the rod is $R = 706 \Omega$. Verify that the resistance contributed by the minority electron carriers is negligible. Assume that each acceptor atom contributes one mobile hole.
8. An open-circuited p-n junction is fabricated from silicon. The number of silicon atoms per m$^3$ is $5 \times 10^{28}$ and the number of acceptors is one atom per $10^{10}$ atoms of silicon. The intrinsic concentration is $n_i = 1.5 \times 10^{16}$ per m$^3$. If the built-in potential is found to be $V_B = 0.5$ V, show that the number of donors is one atom per $4.59 \times 10^{6}$ atoms of silicon.

9. (a) If the acceptor and donor concentrations in a semiconductor are equal, i.e. $N_A = N_D$, show that the hole and electron concentrations must be equal, i.e. $p = n$. (b) If $N_A = N_D$ and the mass-action law holds, show that the doped semiconductor behaves as an intrinsic semiconductor. (c) Use the results of the previous parts to show that the effective impurity concentration in a semiconductor is $N_D - N_A$.

10. (a) A silicon semiconductor has $N_D = 10^{20}$ donor atoms per m$^3$ and $N_A = 7 \times 10^{19}$ acceptor atoms per m$^3$. The intrinsic concentration is $n_i = 1.5 \times 10^{16}$ atoms per m$^3$. The electron and hole mobilities are $\mu_n = 0.13$ m$^2$/V s and $\mu_h = 0.05$ m$^2$/V s. Use the equations $n + N_A = p + N_D$ and $np = n_i^2$ to show that $n = 3 \times 10^{19}$ electrons per m$^3$ and $p = 7.5 \times 10^{12}$ holes per m$^3$. (b) If an applied electric field is $E = 2$ V/cm, show that the current density is $J = 12.5$ mA/cm$^2$. 