Physics 213 **Problem 2** **Week 7**

Law of Mass Action: Charge Carriers in Semiconductors

a) Calculate the intrinsic carrier concentration of silicon at 300 K. What fraction of silicon atoms donates electrons and holes at 300 K? The mass density of silicon is rho_{si} = 2.328 g/cm^3, quantum density of silicon at 300 K is n_q=1.2 x 10^{25} m^{-3}, and the bandgap is delta=1.12 eV.

$$n_i = n_q \exp[-\Delta/(2kT)] = (1.2e25)\exp[-1.12/(2*0.026)]$$

$$= 5.3 \times 10^{15} /m^3$$

We also calculate the concentration of silicon atoms from the mass density giving 5 x $10^{19}/m^3$

This gives us a fraction of 10^{-4}.

b) If we raise the temperature to 310 K, by what factor do we change the intrinsic carrier density?

Plugging into the formula for n_i we get 10.6 x 10^{15} / m^3

This changes by a factor of approximately 2.

c) If instead we wanted the same density of free electrons at 300 K as we have at 310 K, what fraction of silicon atoms need to be replaced with a donor impurity, e.g., phosphorous? In this problem, we want to dope silicon such that the density of electrons at 300 K equals the intrinsic density of electrons at 310 K.

We need 10.6 x 10^{15} / m^3 electrons. Therefore we need 10.6 x 10^{15} – 5.3 x 10^{15} / m^3 electrons. Therefore, we have a fraction of 10^{-4} silicon atoms needing to be replaced.

d) With this many donors, what is the new density of holes in the doped semiconductor?

Here we can use the law of mass action: $n_e\, n_h = ni^2$.

We have that n_e = 10.6 x 10^{15} / m^3 and (from part a) that n_i = 5.3 x 10^{15}/ m^3 . Therefore, n_h= 2.65 x 10^{15}/ m^3.