**Electron – Crystal Interaction**

**The Model**

Here’s our periodic table again,

Table

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Now we’ll take our semiconductors and dope them with impurities. To be clear, when we dope with impurities, typically from columns 13 or 15 of the periodic table, we are *replacing* one of the atoms that was in the crystal lattice with one of the impurities. Doping concentrations ~ 1(impurity)/108(atoms) are considered light. Concentrations ~ 1/104 are considered very heavy. And recall from the Free electrons folder that at room temperature, we can expect there to be about 1 intrinsic electron/1012 atoms. So whether the doping is light or heavy, the number of electron carriers due to impurity doping is vastly greater than that due intrinsically to the semiconductor itself.

This will alter the periodic potential of course. But I guess we can consider the net potential to be the periodic potential plus some difference, which we’ll call the disorder potential, as we did in the metal file. We can imagine periodic potential to come from the imaginary lattice w/o impurities. And the random disorder potential to come from what’s left: basically the potential coming from impurities minus the potential coming from those host atoms whose sites the impurities are technically occupying instead.

So anyway, we’ll consider a bunch of electrons situated within a positive crystal ionic lattice. And add a non-periodic one-particle potential, Vdis(r), from randomly placed impurity atoms in an otherwise periodic system.



We’ll treat the ee interaction as a constant, and the lattice ions as immobile, which makes the ion-ion interaction potential energy constant and neglectable. So then we have:



We’ll simplify further, and presume all the crystal potential does is renormalize the mass m → m\* (but will still call it m). And so we’ll have:



The disorder potential is:



and results from the impurity potentials Vi(r-Rj) stemming from the N impurity sites Rj, j = 1…N. The corresponding second quantized many particle Hamiltonian can be written in the momentum basis as:



where



because (see 2nd quantization file which defines these creation/annihilation operators):



we get:



So there. So far this is the same as what we got for the metals. But there is a little we left out last time, that’s important to include this time. So the impurities will have either one fewer or one more (or if doped with group 12 or 16 atoms, two fewer or two more) valence electrons than the host atom does.

Chart

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And so doping with impurities not only alters the electric potential environment (Vdis) of electrons floating around in the material, but also alters the number of electrons floating around in the environment, as well as minute details about the electric potential within the immediate region of each impurity. When we studied metals, we didn’t bother about the extra electrons added or subtracted (if any) from the material since it wouldn’t have made much difference given the number of conduction electrons in the metal. And neither would’ve the details of the electric potential environment in the close vicinity of each impurity. But it matters now, considering the paucity of such conduction electrons, and so we’ll consider it in more detail when we get to the Excitations file.