Level 3 Condensed Matter Physics- Part II

Examples Class 3
Topic: Semiconductor doping and pn-junctions

(1) *Semiconductor doping*

The density of states $g(E)$ at energy E for a free electron metal is given by:

$$g(E) = \frac{1}{2\pi^2}\left(\frac{2m}{\hbar^2}\right)^{3/2}\sqrt{E}$$

where m is the electron mass.

Consider a semiconductor in equilibrium with chemical potential μ, minimum conduction band energy E_c and maximum valence band energy E_v.

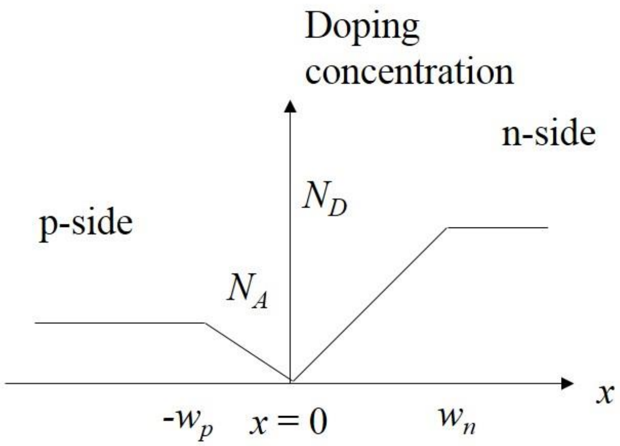
(i) Using the free electron metal density of states write down equivalent expressions for the conduction and valence band density of states in the semiconductor.
(ii) Derive expressions for the equilibrium electron and hole concentrations between energies E and $E+dE$, where dE is a small energy increment.
(iii) If the chemical potential is shifted towards the valence band how would the electron and hole concentrations change?

A Group III impurity is now added to the Group IV intrinsic semiconductor.

(iv) Sketch the variation in majority carrier concentration as a function of temperature clearly labelling the different regimes.
(v) In the saturation regime are the majority carriers electons or holes?
(vi) Calculate the percentage concentration of impurity atoms that must be added in order to achieve a majority carrier concentration of 10^{20} carriers/m^3 in the saturation regime. Assume the semiconductor has a diamond cubic crystal structure with 5.4 Å lattice parameter.
(vii) Calculate the temperature at which the semiconductor shows intrinsic behaviour. Assume E_g = 1.1 eV, $N_c = 2.8 \times 10^{25}$ m^{-3} and $N_v = 1.0 \times 10^{25}$ m^{-3}, where N_c is the effective density of states for the conduction band and N_v is the effective density of states for the valence band.
(viii) If the impurity energy level within the band gap is 10 meV estimate the temperature below which impurity freeze-out takes place.

(2) *pn-junctions*

Consider a pn-junction with the following doping profile, where the donor, acceptor concentrations increase linearly from zero within the space charge region and are constant within the quasi-neutral regions:



The donor, acceptor concentrations at the space charge edges on the *n*-side ($x = w_n$) and *p*-side ($x = -w_p$) are N_D and N_A respectively. Assuming equilibrium and the depletion approximation:

(i) Calculate the electric field distribution within the device.
(ii) By comparing the electric field at $x = 0$ show that charge is conserved for this device.
(iii) Calculate the electrostatic potential as a function of position x.