Exercise 3

Exercise 1: Occupation function of a donor state

In this exercise, you shall calculate step-by-step the occupation function of a donor state starting from the canonical distribution that says: In a system with j states that have the energy E_j, the probability that the system is in state i is given by

$$p_i = \frac{e^{-\frac{E_i}{k_\mathrm{B}T}}}{\sum\limits_j e^{-\frac{E_j}{k_\mathrm{B}T}}}. \tag{1}$$

a) Draw a simplified energy diagram considering a valence band at the energy E_V, a conduction band at E_C, a donor state at E_D, and the Fermi level E_F and give reasonable values for these energies for phosphorous doped silicon.

b) Determine the 3 most probable energy states (consider spin!) and calculate the energies of the system in these states.

c) Calculate the probability that an electron is in the conduction band considering the 3 energy states determined in b).

d) Calculate the electron density in the conduction band assuming a reasonable phosphorus concentration c_P.

e) Compare the result with the Fermi-Dirac distribution.

Exercise 2: Meyer-Neldel behaviour in the conductivity of a-Si:H

The conductivity activation energy E_0 and the conductivity prefactor σ_0 are not independent. Jackson[1] proposed that this relation is a consequence of dispersive transport with a time dependent mobility:

$$\mu(t) = \mu_{00} \cdot (\omega t)^{-\alpha}$$

with $\alpha \stackrel{\mathrm{def}}{=} 1 - T/T_0$.

a) When the mobility is time dependent, the distance travelled by drift in an electric field E is given by:

$$L = \int_0^{t_L} \mu(t') E dt'.$$

Determine the transit time t_L for drift across a sample whose thickness is given by L.

[1] W. B. Jackson, PRB 38(5), p. 3595 (1988)

b) Show that $\mu(t_L)$ can be expressed by

$$\mu(t_L) = \underbrace{\frac{L\omega}{E}(1-\alpha)}_{\mu_0} \cdot \frac{1}{\omega t_L}.$$

c) Insert the relation for t_L obtained from a) into $\mu(t_L)$ from b) to obtain a thermally activated mobility $\mu(t_L)$:

$$\mu(t_L) = \mu_0 \exp\left(-\frac{E_{\text{mob}}}{kT}\right).$$

Make use of the following definition for the activation energy E_{mob},

$$E_{\text{mob}} = kT_0 \ln\left(\frac{\mu_0}{\mu_{00}}\right).$$