Condensed Matter II

Problem set #9

Spring 2023

Hall effect

Isotropic semiconductor

In this section, we study the Hall coefficient in a semiconductor in the presence of both hole and electron charge carriers:

- electron density n_e
- hole density n_h
- electron mobility μ_e
- hole mobility μ_h

(i) Recall the expression of the mobility as a function of relaxation time and effective mass, as well as the expression of the cyclotron frequency.

(ii) Assuming $B = 0.1$ T and $m^* = m_0$, What is the critical relaxation time τ_c below which the weak magnetic field approximation is valid?

(iii) Assuming $\mu_e = 1000\,\text{cm}^2\,\text{V}^{-1}\,\text{s}^{-1}$, is this approximation valid?

(iv) Derive the expression of the resistivity matrix, considering a single carrier species.

(v) Take into account the presence of electrons and holes, and deduce the expression for the Hall coefficient in the material.

Anisotropic case

In this section a single kind of charge carriers (electrons) is present, but its effective mass tensor is anisotropic. Consider a degenerate n-type material with 10^{17} electron carriers per cm^3 in the conduction band. The electrons occupy conduction states associated with the 6 electron carrier pockets of Si. Such carrier pockets are characterized by the mass components $m_t = 0.19m_0$ and $m_l = 0.98m_0$. $\vec{B}$ is along the z axis, $\vec{j}$ is along the x axis, and the relaxation time is τ.

(i) By analogy with the derivation in the isotropic case, establish the expression of the contribution of one electron pocket to the conductivity tensor.

(ii) Deduce from the result of the previous question, the expression for the total conductivity tensor.

(iii) Express the Hall coefficient as a function of the components of the total conductivity tensor, and B.

(iv) Assume the weak field approximation is valid, and deduce the expression of the Hall coefficient as a function of the effective masses, and of the isotropic Hall coefficient.

(v) Derive the expression of the transverse magnetoresistance, and comment on its magnitude.