P.G. Sem III.

MPHYCC11

Condensed Matter Physics

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Electrical Conductivity

As in the free-electron model in which we obtained the result for electrical conductivity

$$\sigma = \frac{ne^2 \tau_F}{m^*} \longrightarrow (1)$$

The quantity n is the concentration of the conduction- or valence-electrons and τ_F is the collision time for an electron at the Fermi surface.

* Electrical conductivity within the framework of Band Theory:

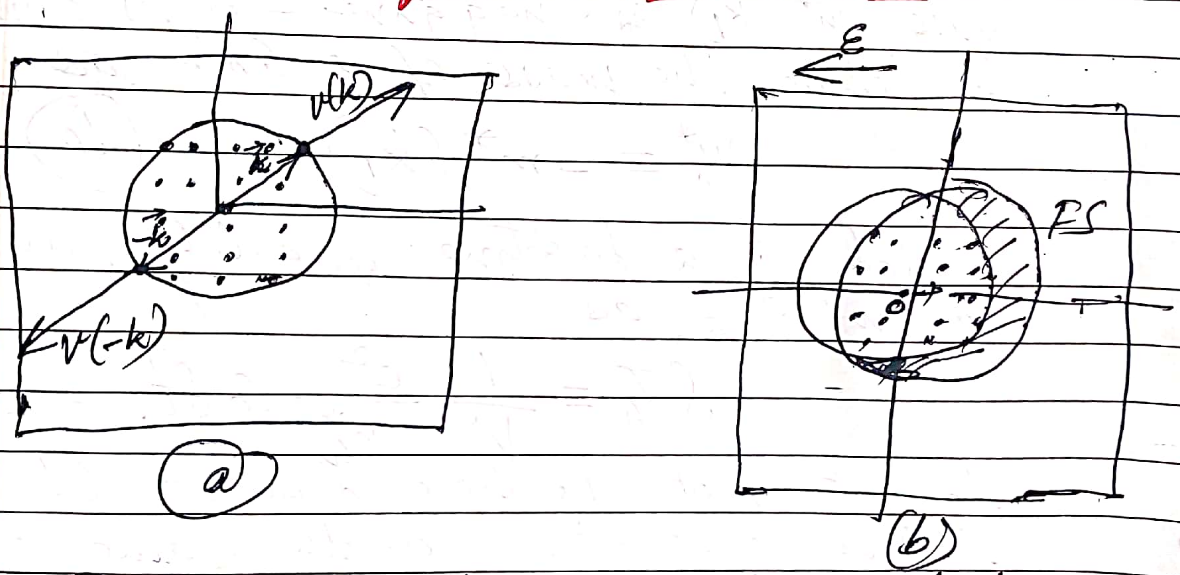

Fig (1) (a) In the absence of an electric field the Fermi sphere is centred at the origin, and the electron currents cancel in pairs. (b) In the presence of an electric field, the Fermi sphere is displaced and a net current results.

When the system is at equilibrium i.e., when there is no electric field; the Fermi surface is centred exactly at the origin, as shown in Fig. 1 (a). Consequently, the net current is zero, because the velocities of the electrons cancel in pairs. That is, for every electron in state $\vec{k}$ whose velocity is $\vec{v}(\vec{k})$, another electron exists in state $-\vec{k}$ whose velocity $v(-k) = -v(k)$ is simply the reverse of the former. This result, found in the free-electron model, also holds good in band theory, and accounts for the vanishing of the current at equilibrium.

When an electric field is applied, each electron travels through k-space at a uniform rate that is;

$$\delta k_x = -\frac{e\mathcal{E}}{\hbar}\,\delta t,$$

where δk_x is the displacement in a time interval δt. Since an electron usually "lives" for an interval equal to the collision time τ, the average displacement is

$$\delta k_x = -\frac{e\mathcal{E}}{\hbar}\,\tau. \longrightarrow (2)$$

Consequently the Fermi Surface is displaced rigidly by this amount, as shown in Fig. 1(b). There are now some electrons which are not compensated - i.e., cancelled by other electrons, and which are indicated by the cross-hatched crescent-shaped region. They contribute a net current.

The density of this current can be calculated as follows: It is given by

$$J_x = -e\,\overline{V_{F,x}} \times \text{Concentration of uncompensated electrons}$$

$$= -e\,\overline{V_{F,x}}\, g(E_F)\,\delta E$$

$$= -e\,\overline{V_{F,x}}\, g(E_F)\left(\frac{\partial E}{\partial k_x}\right)_{E_F}\delta k_x, \longrightarrow (3)$$

where $\overline{V_{F,x}}$ is the component of the Fermi velocity in the x-direction and the bar indicates an average value.

To note that $g(E_F)\delta E$ gives the concentration of uncompensated electrons, $g(E_F)$ being the density of states at the FS and δE the energy absorbed by the electron from the field. Noting that $\partial E/\partial k_x = \hbar v_{F,x}$, and substituting ~~from~~ δk_x from Eq. (2) one has

$$J_x = e^2 \bar{v}_{F,x}^2 \tau_F g(E_F)\mathcal{E}, \quad (4)$$

where the collision time has been designated