

Solutions to Problems in Solid State Physics II

Problem 2005-I

ε_A is the maximum energy of band 1 (follows from the specification of the Fermi surface). The number of electronic states in one band, within the 1. Brillouin zone, is twice the number of k states, i.e. twice the number of unit cells in the system. If $\varepsilon_h < \varepsilon_e$ all states in band 1, and no states in band 2, would be occupied by electrons at zero temperature, implying that

1) the system would be an insulator (or semiconductor).

The reciprocal lattice of an fcc is a bcc lattice. In the bcc reciprocal lattice there are 8 equivalent (111) reciprocal lattice points lying at the corners of the 1. Brillouin zone, each counting one-eighth. This implies that there is, effectively, one hole and one electron Fermi surface in one Brillouin zone. With the use of the notation introduced on the figure, we have:

$$\varepsilon_F = \varepsilon_e + \frac{(\hbar k_e)^2}{2m_e} = \varepsilon_h - \Delta + \frac{(\hbar k_h)^2}{2m_h}, \quad \varepsilon_F = \varepsilon_h - \frac{(\hbar k_h)^2}{2m_h}. \quad (1)$$

The number of holes (i.e. the number of missing electrons) in band 1 is equal to the number of electrons occupying band 2, i.e.

$$n = p. \quad (2)$$

and since both bands are parabolic, we may use Marder eq. (6.29) to obtain the lengths of the two Fermi wave vectors:

$$k_e = (3\pi^2 n)^{1/3}, \quad \text{and equivalently} \quad k_h = (3\pi^2 p)^{1/3}. \quad (3)$$

These equations are straightforwardly solved, and we get

$$2) \quad \varepsilon_F = \varepsilon_A - \frac{m_e}{m_e + m_h} \Delta.$$

$$3) \quad n = p = \frac{1}{3\pi^2} \left(\frac{2\Delta}{\hbar^2} \frac{m_e m_h}{m_e + m_h} \right)^{3/2}.$$

According to Marder eqs. (6.77) and (6.23), the specific heat is

$$c_V = \frac{\pi^2}{3} k_B^2 T D(\varepsilon_F), \quad D(\varepsilon_F) = \frac{m}{\hbar^3 \pi^2} \sqrt{2m\varepsilon_F} = \frac{mk_F}{\hbar^2 \pi^2}, \quad (4)$$

in the case of a parabolic band, when $T \ll \varepsilon_F/k_B$. In the present case, we need to require $T \ll \Delta/k_B$, and adding the electron- and hole-like contributions,

$$D(\varepsilon_F) = \frac{m_e k_e}{\hbar^2 \pi^2} + \frac{m_h k_h}{\hbar^2 \pi^2} = \frac{m_e + m_h}{\hbar^2 \pi^2} \left(\frac{2\Delta}{\hbar^2} \frac{m_e m_h}{m_e + m_h} \right)^{1/2} \quad (5)$$

the result is

$$4) \quad \gamma = c_V/T = \frac{k_B^2}{3\hbar^2} \sqrt{2m_e m_h (m_e + m_h) \Delta}.$$

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