Slides
Condensed Matter Physics
Revision Lecture 2

One More Revision Lecture on Weblearn

2014 Revision Lecture 1

Covers

Revision Homework 6.6

2007 Exam Question 1

(2014 Revision Lecture 2 is dead link?)

2. Derive expressions for the Fermi Temperature, T_F, and Debye Temperature, θ_D, of a monovalent metal containing n atoms per unit volume, and within which the speed of sound averaged over polarisations is c. Show that for a face-centred cubic metal with lattice spacing a the ratio of the two temperatures is given by

$$\frac{T_F}{\theta_D} = (6\pi^2)^{1/3}\left(\frac{\lambda}{a}\right) \quad ,$$

where $\lambda = \hbar/(2m_e c)$. [10]

The effective speed of sound in copper (which is a face-centred cubic monovalent metal) is $2700\,\mathrm{m\,s^{-1}}$, and the ratio T_F/θ_D is 240. Calculate T_F, θ_D, and a. [3]

A metal is at a temperature of order θ_D. Within the metal, an electron with the Fermi wave vector, $\mathbf{k_F}$, scatters from a phonon of wave vector $\mathbf{k_{ph}}$ and loses energy. Its new wave vector is $\mathbf{k}'$. Explain why the magnitude of the new wave vector is very close to that of the original wave vector, i.e. $|\mathbf{k}'| = (1-\delta)|\mathbf{k_F}|$, where $\delta \ll 1$. Assuming the phonon obeys the dispersion relation $\omega_{\mathrm{ph}} = ck_{\mathrm{ph}}$ show that

$$\frac{1}{2\delta}\left(\frac{k_{\mathrm{ph}}}{k_{\mathrm{F}}}\right)\frac{1}{k_{\mathrm{F}}} \approx \lambda \quad .$$

[8]

What does the length λ represent? [4]

Why this problem is totally incorrect as stated !!!

3. State what you understand by the terms *intrinsic semiconductor*, *extrinsic semiconductor*, *mobility*, and *effective mass*. [4]

Intrinsic Semiconductor = A semiconductor with dopant density *less than* the density of thermally excited carriers (if the system had no dopants.)

Extrinsic Semiconductor = A semiconductor with dopant density *more than* the density of thermally excited carriers (if the system had no dopants.)

Effective mass : If electron has dispersion E(k),

electron effective mass is given by

$$\frac{\hbar^2}{m_e^*} = \frac{\partial^2 E}{\partial k^2}$$

hole effective mass is given by

$$\frac{\hbar^2}{m_h^*} = -\frac{\partial^2 E}{\partial k^2}$$

Mobility = ??

3. State what you understand by the terms *intrinsic semiconductor*, *extrinsic semiconductor*, *mobility*, and *effective mass*. [4]

Explain what is meant by a *hole* in semiconductor physics, and why it is a useful concept.

Hole = Absence of an electron in an otherwise filled band

3. State what you understand by the terms *intrinsic semiconductor*, *extrinsic semiconductor*, *mobility*, and *effective mass*. [4]

Explain what is meant by a *hole* in semiconductor physics, and why it is a useful concept. Give arguments that determine the sign of (i) the effective mass, (ii) the charge associated with the hole. [6]

For the majority of intrinsic semiconductors, the mobility of the electrons is greater than that of the holes. Give a simple argument that explains why this is the case. For pure germanium at room temperature the mobilities of the electrons and holes are 0.36 and $0.18\,\mathrm{m^2\,V^{-1}\,s^{-1}}$ respectively, and the electrical resistivity is $0.5\,\Omega\,\mathrm{m}$. What is the number density of electrons and holes? [6]

A monovalent face-centred-cubic metal with lattice parameter 0.36 nm has a resistivity of $1.7\times10^{-8}\,\Omega\,\mathrm{m}$. Calculate the mobility of the electrons, and comment on the value compared with the mobility of the electrons in germanium. [5]

The two ends of a piece of intrinsic germanium with cross-sectional area $1\,\mathrm{mm}^2$ and length 1 cm are connected to the terminals of a 2 V battery by means of wires made from the above-mentioned metal. The wires have cross-sectional area of $0.5\,\mathrm{mm}^2$. Determine the drift velocity of the carriers in the germanium, and of the carriers in the metal. [4]

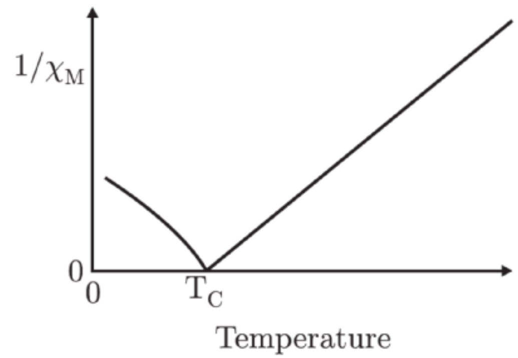
4. Define *magnetic susceptibility*, χ_M. Consider a crystal containing N paramagnetic ions per unit volume, each of which has a spin $S = 1/2$. The crystal is placed in a magnetic field of flux density B and is at a temperature T. Show that in the limit of small B, and assuming non-interacting spins,

$$\chi_M = \frac{N\mu_0\mu_{\mathrm{B}}^2}{k_{\mathrm{B}}T} \quad .$$

What is meant by a small magnetic field in this context? [6]

Relaxing the assumption of non-interacting spins, make an estimate of the magnetic field due to one of the ions that is experienced by its neighbour, situated at a distance of order 0.2 nm. Hence estimate the temperature such that the thermal energy of an ion is equivalent to the magnetic interaction energy between neighbouring ions. [5]

The figure shows the inverse magnetic susceptibility as a function of temperature for a different magnetic material that can exhibit a permanent magnetic moment over a certain temperature range. State this temperature range, and outline a simple model that explains the temperature dependence of χ_M for $T \geq T_C$. Given that for certain such materials, $T_C \approx 1000\,\mathrm{K}$, describe a physical mechanism that could account for the magnitude of T_C. [10]



In practice macroscopic samples of the material often display a permanent magnetic moment that is far lower than the theoretical maximum value. Explain why this is the case. [4]