University of Zurich[UZH]

Solid State Physics
Exercise Sheet 11

FS16
Prof. Dr. Johan Chang

Discussion on 11th May

Due on 18th May

Exercise 1 *Tight binding model*
In the lecture, we derived the tight-binding expression for a two-dimensional square lattice:

$$\epsilon_k = -\epsilon_0 - 2t[\cos(k_x a) + \cos(k_y a)] \tag{1}$$

(a) Plot, using your favourite computer program, (1) the full three-dimensional band structure ϵ_k versus k_x and k_y, (2) the band structure along the zone diagonal $k_x = k_y$, and (3) the Fermi surface ($\epsilon_k = \epsilon_F$) for systems with $\mu = \epsilon_F$ having the values $-\epsilon_0$ and $-\epsilon_0 \pm 2t$ [Hint: Set $t = 1$ meaning that ϵ_k is plotted in units of t and set $\epsilon_0 = 0$].

(b) In the lecture, we developed the tight binding only to first order. Let's include second order terms. We define t' as the integral over next-nearest neighbours that are given by $R_m = \{\pm a, \pm a\}$ and $\{\pm a, \mp a\}$. Show that the tight-binding dispersion becomes:

$$\epsilon_k = -\epsilon_0 - 2t[\cos(k_x a) + \cos(k_y a)] - 4t'[\cos(k_x a)\cos(k_y a)] \tag{2}$$

(c) Let's say that $\mu = -\epsilon_0 - 0.87t$. Compare the Fermi surfaces for $t' = 0$ and $t' = -0.2t$.

Exercise 2 *Quantum oscillations on quasi two-dimensional systems*
In $Tl_2Ba_2CuO_{6+\delta}$, quantum oscillations with a frequency of $F = 18.1\,\mathrm{kT}$ are observed (B. Vignolle et al., Nature **455**, 952-955 (2008)).
(a) Use the Onsager relation ($S = 2\pi\frac{eF}{\hbar}$) to calculate the Fermi surface area.
(b) If we assume a circular Fermi surface shape what is the Fermi momentum?

Exercise 3 *Quantum oscillations in gold*
Estimate the Fermi energy of gold (in eV) based on the oscillations of the spin susceptibility in a magnetic field, see figure 1. Which of the two superimposed oscillations corresponds to the largest orbit on the Fermi-sphere? Compare the result with the literature value $\epsilon_F = 5.51\,\mathrm{eV}$. Where is the other oscillation originating from?

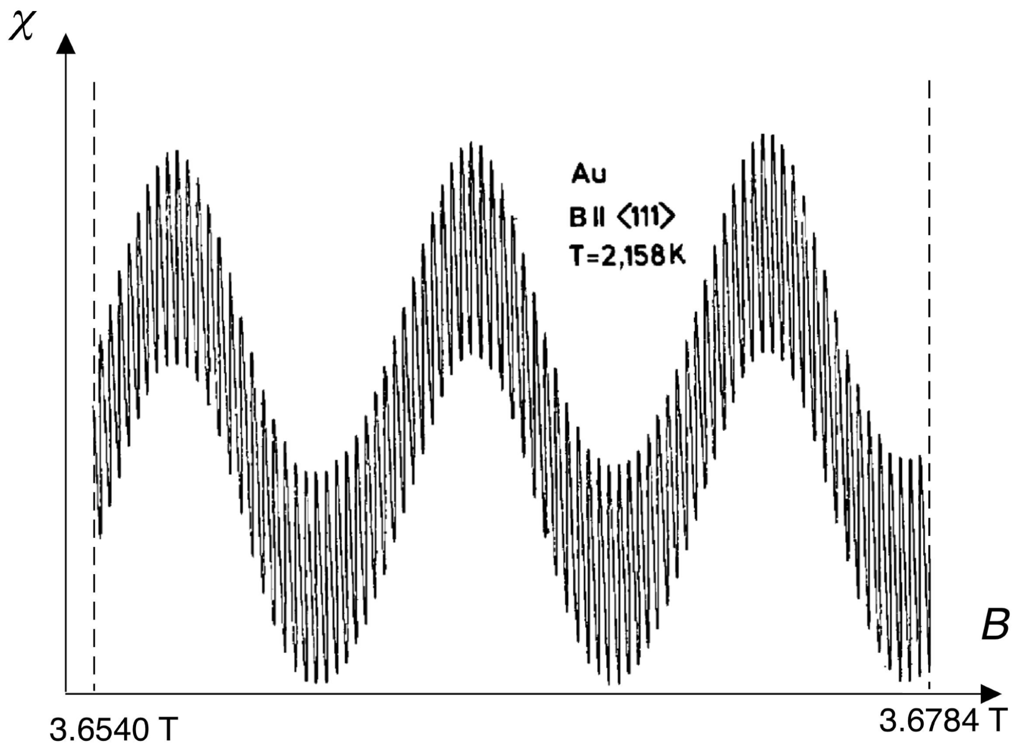

Figure 1: The spin susceptibility of gold in a magnetic field.