Problem set 1

Deadline 05.03.2025

Use the material from
V.F.Gantmakher "Electrons and Disorder in Solids", Chapter 1
A.A. Abrikosov "Fundamentals of Theory of Metals", Chapter 3

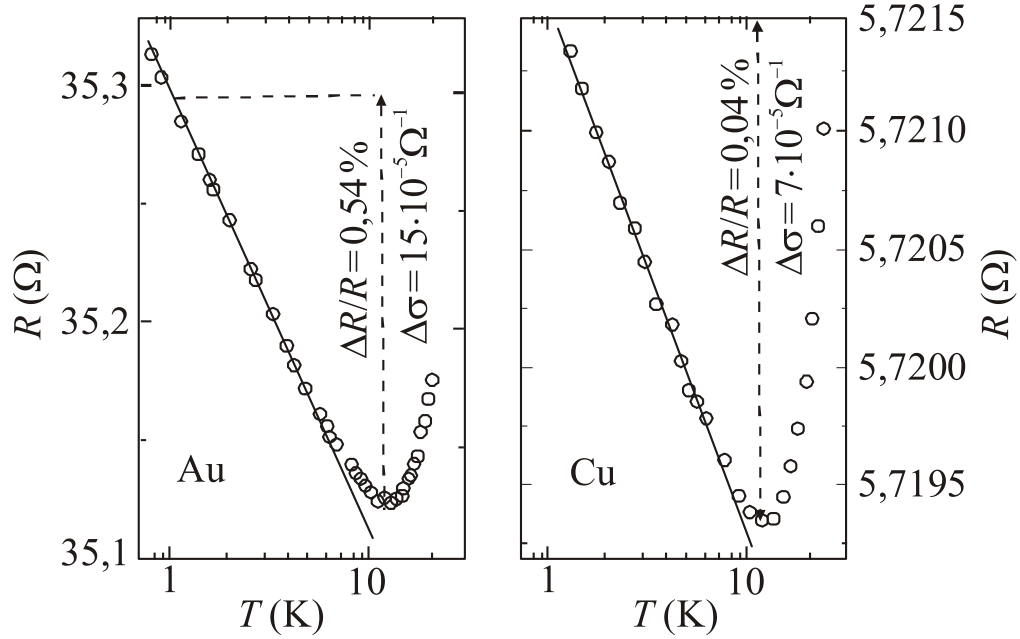
1. Derive the expression for electronic diffusion coefficient D in a metal (consider two- and three-dimensional cases). Derive the Einstein relation between D and electrical conductivity. Estimate resistivity of a typical metal (take Cu or Au as an example) assuming the mean free path ~ 100 nm.

2. Plot schematically temperature dependence of electrical resistivity for a typical metal and discuss its main features in terms of various mechanisms of electronic scattering (impurities, electron-electron and electron-phonon interaction).

Problem set 2
Deadline 17.03.2025

1) Using the weak localization theory, explain the main features of the experimental data shown below

Au – S.I. Dorozhkin, *et. al.,* JETP Lett. **36,** 15 (1982)
Cu – L.Van der Dreis *et. al.,* PRL **46,** 565 (1981)



2) Using the above data, estimate the electronic mean free path *l* and the phase breaking length L_φ in Au and Cu at T = 2 K.

3) For both films, plot qualitatively the dependence of the resistance on magnetic field at T=2K. How it depends on a magnetic field direction ?

4) Prove that the condition $\Omega\tau << 1$ is fulfilled,
where Ω is the cyclotron frequency, corresponding to the magnetic field B_φ .

5) Discuss possible ways of experimental determination of the phase breaking length L_φ

Problem set 3

Deadline 10.04.2025

1. Estimate a Coulomb gap in a material with permittivity κ=10
   (a) in 3D regime with carrier concentration 10^{16} cm^{-3}
   (b) in 2D regime with carrier concentration 10^{12} cm^{-2}.

2. Consider thin film with thickness 100 nm, permittivity κ=10, concentration of carriers 10^{18} cm^{-3} and effective mass $0.1m_e$. Estimate crossover temperature when electronic hopping behaviour changes from three-dimensional to two-dimensional regime i.e. when the resistivity behaviour changes from $\rho = \rho_0 \exp(T_M / T)^{1/4}$ to $\rho = \rho_0 \exp(T_M / T)^{1/3}$.

3. Derive the expression (or explain the main steps in its derivation) for the screening length given by Eq.5.42 in Gantmakher's book.
   Hint: the discussion for two dimensions can be found e.g. on pp.73-74 in Datta's textbook "Electronic transport in mesoscopic systems".

4. Show that dimensionless conductance y defined by Eq.6.1 in Gantmakher's book is the ratio of Thouless energy and mean level spacing for any sample dimensionality. Discuss the physical meaning of Thouless energy.