Problem set 1

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

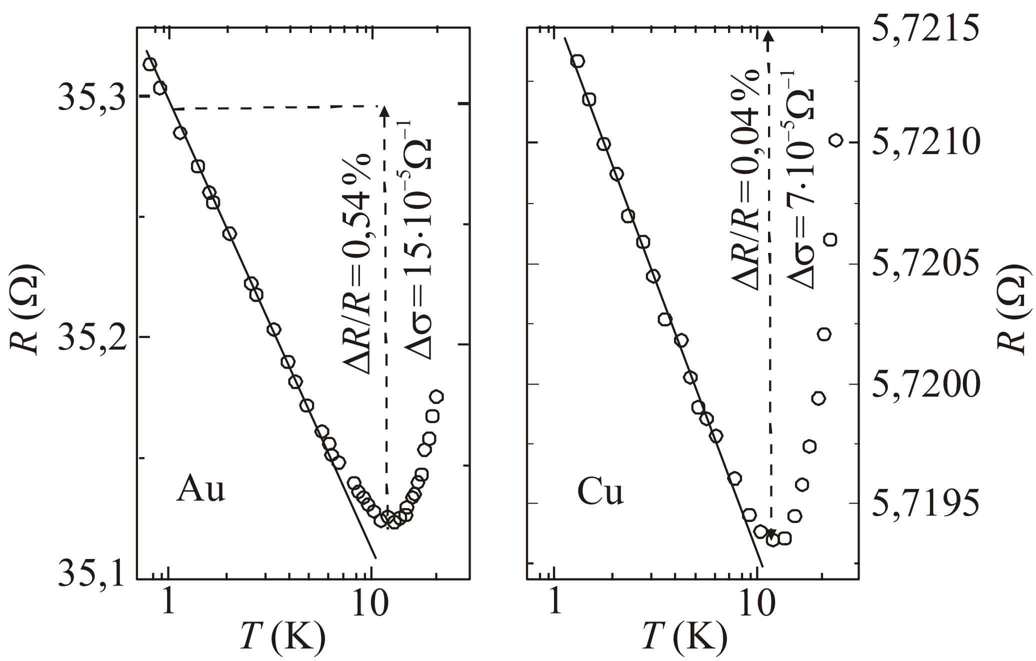
- Derive the expression for electronic diffusion coefficient *D* in a metal (consider two- and three-dimensional cases). Derive the Einstein relation between *D* and electrical conductivity. Estimate resistivity of a typical metal (take Cu or Au as an example) assuming the mean free path ~ 100 nm.

- 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).

Preoblem set 2

- 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)



- Based on the above data, estimate the electronic mean free paths and the phase breaking lengths in Au and Cu at T = 2 K.

- For both films, sketch the dependence of the resistance on magnetic field at T=2K for several magnetic field directions.
Prove that the condition $\Omega\tau \ll 1$ is fulfilled,
where Ω is the cyclotron frequency, corresponding to the magnetic field B_φ.

- Discuss possible ways of experimental determination of the phase breaking length

Problem set 3

- 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}.

- 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

$$\rho = \rho_0 \exp(T_M / T)^{1/3}$$

.- 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".

- 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.