Physics of Materials and Nuclei

Dr. Shail Pandey
Department of Physics
SVNIT Surat

Free Electron Gas Theory

Drude Model

- Provides a classical mechanics approach to describing conductivity in metals.
- Electrons in a metal behave much like particles in an ideal gas (no Coulombic interaction and no collisions between particles - reasonably valid). This is called the *independent electron approximation*.
- Positive charges are located on immobile ions. The electrons do not experience coulombic interaction with the ions (completely invalid), but they do collide with the ions and can change direction and velocity.

- Electrons reach thermal equilibrium by collisions with the ions – they emerge after collision at a random direction with speed appropriate to the temperature of the region where collision happened.
- That is, these collisions preserve local thermodynamic equilibrium: when the electrons emerge from a collision, they do so with a speed that is entirely determined by the local temperature and in a random direction. This velocity is assumed to be entirely independent of the electron velocity prior to collision
- Without any electric field, electrons move along a straight line between collisions
- Mean free time/Relaxation time is independent of electron's position or velocity (a good assumption).
- Model explains –
  - electrical transport in metals
  - thermal conductivity of metals

$$\sigma = \frac{ne^2\tau}{m_e}, \quad \rho = \frac{m_e}{ne^2\tau}$$

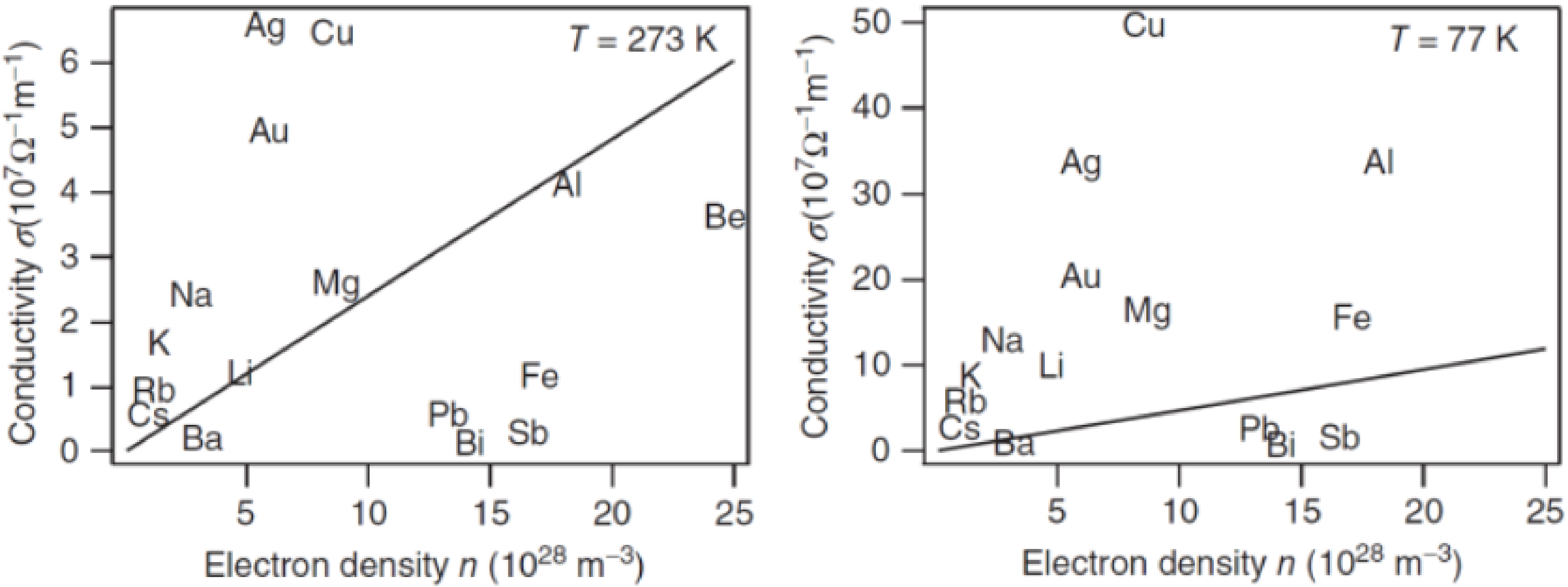

Figure 1 Measured and calculated conductivities for various metals at 273 K (left) and 77 K (right) as a function of electron density. The black lines indicate conductivities computed via the Drude model while the names of the metals indicate measured conductivities. Note that the calculations assume mean free paths of 1 nm and that the model loses efficacy at lower temperatures.

$$\frac{\kappa}{\sigma} = \frac{3k_B^2 T}{2e^2} = LT$$

- This model outline of metallic conductivities were developed by P. Drude in 1900.
- The model produced a number of successes in describing the properties of metals, and even today is useful for simple descriptions of metallic conductivity, as well as for roughly estimating properties.
- The Drude model, however, failed to describe a number of experimental observations.

Shortcomings of the Drude Model

The Drude model does not take into account

- Collisions between electrons themselves.
- Electrostatic interactions between the electrons and the lattice ions.
- The de Broglie wavelengths of electrons with some thermal energy are on the nanometer scale => the electrons cannot be treated as classical particles (since they have substantial wave character) under the conditions of the Drude model.
- The assumption of a constant mean free path (based on atomic spacing) is incorrect. The mean free path varies greatly with temperature, particularly in pure crystalline substances → the model, therefore, underestimates conductivity of metals at low temperatures

Shortcomings of the Drude Model

- The Drude model cannot explain the conductivity of alloys.
  - Even small impurities can drastically decrease the conductivity of metals in a way which is not predicted by the Drude model.