Nalanda Open University
B.Sc. Part-III

Course – Physics
Paper – VIII

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Topic – Drude-Lorentz theory:- The basic assumption of this theory are:

- There are a large number of free electrons in a metal. These electrons are free to move about the whole volume of the metal like the molecules of a perfect gas in a container.
- The free electrons make collision from time to time with fixed positive ions in the lattice and also among themselves. We may neglect the collisions between electrons in comparison with the collisions between electrons and ions cores.
- In the absence of electric field, the random motion of free electrons is equally probable in all directions so that current density vector is zero.
- When an external electric field is applied, the electrons drift slowly with some average velocity, known as average drift velocity in the direction opposite to that of electric field. The drift velocity of free electrons is superimposed over their random velocity. The continuous solid lines show a possible random path followed by an electron in the absence of an applied field. The dashed lines show the electron path in the presence of the electric field E. The drift velocity is much smaller in magnitude than average random velocity of free electrons.
- The average distance transverse by a free electron between two successive collision with the positive ions is called mean free path and is denoted by λ. .

  If an electron of mass m and charge e is placed in an electric field E, it experiences an acceleration 'a' given by;

  $$a = e\,E/m.$$

  Let τ be the average time-interval between two successive collisions of an electron with positive ions. Increase in drift velocity in time-interval between two successive collisions of an electron with positive ions. The drift velocity is reduced to zero at the next collision and again builds up to the value $eE\tau/m$ before suffering another collision and so on. Therefore, the average drift velocity through the

$$\text{Conductor} = V_d = eE\tau/2m.$$

Let n be the number of conduction electrons per unit volume.

Current density = $J = n\,e\,v_d = n\,e\,2E\tau/2m$

But, $J = \sigma = J/E = ne\,2\tau/2m$

This is the expression for the electrical conductivity of a metal.

Wiedmann-Fraz relation between thermal and electrical conductivities on the basis of Drude- Lorentz theory:-

Thermal conductivity:- Heat transfer by conduction involves transfer of energy within a material without any motion of the material as a whole. The rate of heat transfer depends upon the temperature gradient and the thermal conductivity of the material. Metals are much better thermal conductors than non-metals because the same mobile electrons which participate in electrical conduction also take part in the transfer of heat.

Power per unit area transported is $\Delta Q/\Delta t = -K(\Delta T/\Delta x)$

Where, K is thermal conductivity and $\Delta T/\Delta x$ is temp. gradient.

At a given temperature, the thermal and electrical conductivities of metals are proportional, but raising the temperature increases the thermal conductivity while decreasing the electrical conductivity. This behavior is quantified in the Wiedmann-Fraz Law:-

$$K/e = LT$$

or, $L = K/\sigma T$ Wiedmann-Franz Law

where, K= thermal conductivity
σ = electrical conductivity
L= Lorenz number

The relationship is based upon the fact that the heat and electrical transport both involve the free electrons in the metal. The thermal conductivity increases with the average particle velocity that increases the forward transport of energy. However, electrical conductivity decreases with particle velocity increases because the collisions divert the electrons from forward transport of charge. This means that the ratio of thermal to electrical conductivity depends upon the average velocity squared, which is proportional to the kinetic temperature. The molar heat capacity of a classical mono-atomic gas is given by

$$CV = \frac{3}{2} R = \frac{3}{2} N_A k$$

Now, the expression for thermal and electrical conductivity become,

Conductivities for thermal, $K = \frac{n(v)\,\lambda\,K}{2}$

Conductivities for electrical , $\sigma = n e^2 \lambda/m(v)$

Using the expression for mean particle speed from Kinetic theory

$$(v) = \frac{(8kT)^{1/2}}{\pi m}$$

The ratio of thermal to electrical conductivity illustrates the Wiedmann-Franz Law

$$k/\sigma = 4k^2T/\pi e^2$$

or, $k/\sigma = LT$

Here, the value of the constant is in error in this classical treatment.

When the quantum mechanical treatment is done, the value of the constant is

$$L = k/\sigma T = \pi^2 k^2/3e^2 = 2.45\times10^{-8}\ \text{w}\Omega/\text{K}^2$$