Thermal Physics (Heat)
Wiedmann Frantz Law

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Wiedmann – Franz law : Relation between thermal and electrical conductivity

This law is stated as

" The ratio between thermal and electrical conductivities at a given temperature is same for all metals "

i.e., $\frac{K}{\sigma}$ = constant

where K and σ are the thermal and electrical conductivity of metals.

This is Known as Wiedmann – Franz law .

This law was extended by Lorentz and stated as

" The ratio between thermal and electrical conductivities is proportional to absolute temperature T "

$$\frac{K}{\sigma T} = \text{constant} \qquad (1)$$

Drude applied the free electron gas model to explain the empirical law. In metal , the electrons in the outer most orbit of the atoms are weakly bound .

So the electrons are free to move in the metal .

These free electrons in metal behave like gas molecules

and in equilibrium with the atoms .

Drude assumed that free electrons are responsible for both the

thermal and electrical conduction in metals .

The drift velocity of these electrons in any direction under the influence of a potential difference constitute electrical conductivity.

In the absence of an electrical, these electrons are assumed to possess the velocity of thermal agitation only .

The transfer of energy of thermal agitation in any direction is thermal conduction .

When an electric field is applied in a conducting material , the free electrons move in the positive direction on field and produce an electric current .Let E be an electric field intensity , then an electron of charge e and mass m will experience a force eE and develops an acceleration ,

$$f = \frac{eE}{M} \qquad (2)$$

Let λ be the mean free path and v be the mean velocity of the electron at temperature T . The electron is accelerated between two collisions but loses its velocity on collision with the atom .

The time taken between two successive collisions is

$$t = \frac{\lambda}{v}$$

Since , initial velocity is zero

From basic formula , v = u + ft

Final velocity   =   ft   = $\frac{\lambda\, eE}{mv}$

So the mean velocity

$$u = \frac{\lambda e E}{2mv} \qquad (3)$$

if we consider n be the number of electrons per unit volume , then number of electrons per unit area per second is

$$nu$$

Hence the current per unit area is given by

$$i = neu \qquad (4)$$

The electrical conductivity σ per unit area per unit cross sectional area is given by

$$\sigma = \frac{i}{E} = \frac{n\lambda e2}{2mv} \qquad (5)$$

From law of equipartition energy ,Drude assumed

$$\frac{1}{2}\ mv^2 = \frac{3kT}{2}$$

$mv = \frac{3kT}{v}$ substituting this value in (5) we get ,

$$\sigma = \frac{n\lambda e2}{6mv} \qquad (6)$$

Thermal conductivity which arises due to thermal agitation in conductor is given by

$$K = \frac{nv\lambda}{3J}\frac{dU}{dT}$$

From law of equipartition of energy

$$U = \frac{3}{2} kT$$

$$\frac{dU}{dT} = \frac{3}{2} k$$

Thermal conductivity, $K = \frac{nv\lambda k}{2J}$ (7)

Where J = Mechanical equivalent of heat , k = Boltzmann constant.

From (6) and (7) we get

$$\frac{K}{\sigma T} = \frac{3}{j}\left(\frac{k}{e}\right)^2 = \text{constant} \quad (8)$$

This law is extended from of Wiedmann- Franz to Lorentz law .

This equation (8) was experimentally tested by

Jaeger ,Diesselhorst and Lees

found that good for pure metals at ordinary temperatures

but decreases at lower temperature.