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ELECTRICAL ENGINEERING

Material Science

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- Theory
- Explanation
- Derivation
- Example
- Shortcuts
- Previous Years Question With Solution

2020 Technical Material science for ECE and EEE

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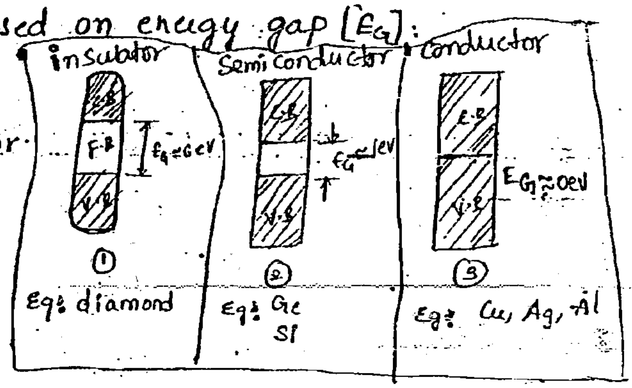
Basics of material science.

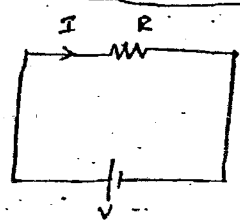
2. Conductor Materials

Note: Classification of materials based on energy gap [E_G]:

1) Insulator
2) Semi-conductor
3) Conductor



Ohm's Law Of Electricity :-



V is the applied voltage

I is the produced current

R is the resistance of a resistor

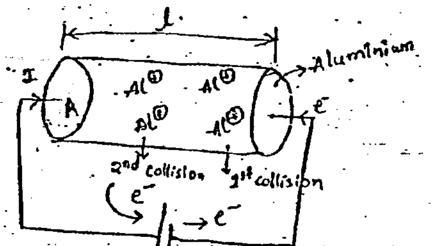
$$R = \frac{l}{\sigma A} = \frac{\rho l}{A} \ (\text{ohm})(\Omega)$$

$\sigma \rightarrow$ electrical conductivity $\left(\frac{1}{\Omega m}\right)$

$$\sigma = \frac{l}{RA} \left(\frac{m}{\Omega m^2} = \frac{1}{\Omega m}\right)$$

$\rho \Rightarrow$ electrical resistivity (Ωm)

$$\rho = \frac{1}{\sigma}$$



l = length of conductor

A = Cross sectional area

According to ohm's law $V \propto I$

$$V = \text{constant} \times I$$

$$V = RI \quad \text{—①}$$

$$V = \frac{l}{\sigma A} I \Rightarrow \frac{I}{A} = \sigma \frac{V}{l} \Rightarrow \boxed{\vec{J} = \sigma \vec{E}} \text{—②}$$

Force on electron having 'm' mass and acceleration 'a' is

$$F = ma \quad \text{—③}$$

Force on electron having 'q' charge due to applied electric field intensity 'E' is $\vec{F} = q\vec{E} \rightarrow ④$

$③ = ④ \Rightarrow ma = qE \Rightarrow a = \frac{qE}{m}$ —— ⑤

Drift velocity $v_d = a\tau_c$ —— ⑥

$\left(\frac{m}{sec}\right) \quad \left(\frac{m}{s^2}\right)(s)$

Put ⑤ in ⑥

$$v_d = \frac{qE}{m}\tau_c$$

$$\vec{v}_d = \left(\frac{q\tau_c}{m}\right)\vec{E} \quad \text{—— ⑦}$$

E = electric field intensity $\left(\frac{V}{m}\right)$

$$\boxed{\vec{v}_d = \mu\vec{E}}$$

$$\boxed{\mu = \text{mobility} = \frac{q\tau_c}{m} \left[\frac{m^2}{(\text{Volt})(\text{sec})}\right]}$$

$$\vec{J} = nq\vec{v}_d \quad \text{—— ⑧}$$

$\left(\frac{A}{m^2}\right) \quad \left(\frac{1}{m^3}\right)(C)\left(\frac{m}{sec}\right)$

Put ⑦ in ⑧

$$\vec{J} = nq\mu\vec{E} \quad \text{—— ⑨}$$

Compare ② and ⑨

$$\sigma = nq\mu \quad \text{—— ⑩}$$

$$\sigma = nq\left(\frac{q\tau_c}{m}\right)$$

$$\boxed{\sigma = \frac{nq^2\tau_c}{m}}$$

n = electron density = $\frac{\text{number of electrons}}{m^3}$ $\left(\frac{1}{m^3}\right)$

q = charge of charge particle.

m = mass of charge particle.

τ_c = collision time (second).

τ_c is the average time b/w two successive collisions

NOTE: ** ① In conductor (or) metals when temperature is increased metal ions vibrate and number of collisions increase and collision time decreases, so conductivity decreases and resistivity increases. Metals have positive ~~temperature~~ coefficient of resistivity and resistance.

It is found that $\tau_c \propto \frac{1}{\sqrt{T}}$

$$\sigma \propto n\tau_c$$

$$\sigma \propto \frac{n}{\sqrt{T}}$$

T = temperature

Factors affecting the resistivity:

*① **temperature (T)**: In conductor the temperature is increased the ρ increase according to the following equation.

$$\boxed{\rho_T = \rho_{RT}(1+\alpha\Delta T)} \quad \text{—— ①} \quad \text{also } \boxed{R_T = R_{RT}(1+\alpha\Delta T)}$$

ρ_T = ~~resistivity of operating temperature~~

ρ_{RT} = Resistivity at room temperature (T_{RT})

$\Delta T = T - T_{RT}$

ΔT = change of temperature

α = temperature coefficient of resistivity ($^{1}/_{^\circ C}$ or $^{1}/_{^\circ K}$)

α is positive for metals

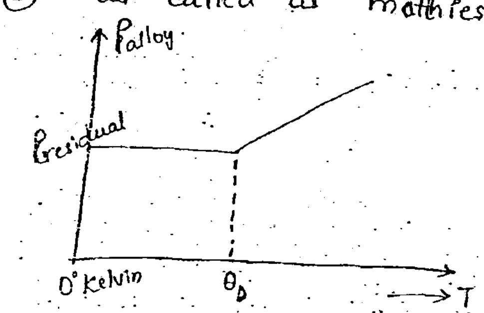
$R_T \Rightarrow$ Resistance at T temperature
$R_{RT} \Rightarrow$ Resistance at Room temp (or) Reference temp.
$\Delta T = T - T_{RT}$ = change of temp
α = temperature coefficient of Resistance (R)

*② **Alloying Effect**: Adding impurity atoms to pure metals.

If percentage of alloy content is increased then irregular in atomic arrangement increases, so resistivity increases (independent of temperature) This is called as residual resistivity ($\rho_{residual}$)

Total resistivity is $\boxed{\rho_{alloy} = \rho_{thermal} + \rho_{residual}}$ —— ②

Eqn ② is called as matthiessen rule.



θ_D is called as Debye temperature. It is the temperature after which ρ increases linearly w.r.t temperature

3) ** Deformation :

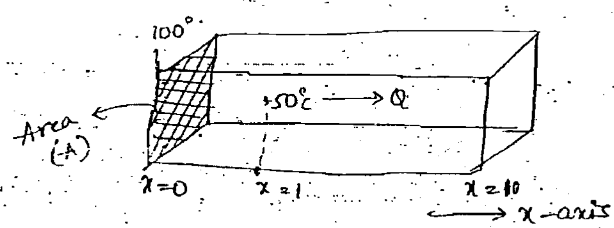
Deformation → change of shape (or) length (or) diameter (or) volume.

⇒ Deformation in conductors increase the Irregularity of atomic arrangement. So ρ increases. This increase of ρ is called as $\rho_{deformation}$ for alloy having deformation

Total resistivity $\rho_{alloy} = \rho_{thermal} + \underbrace{\rho_{residual} + \rho_{deformation}}_{\text{permanent i.e independent of temperature}}$

Observation :

1) In conductors (or) metals thermal energy is transferred due to random motion of free electrons as well as vibrations of metal ions. But most of the % of ~~thermal~~ energy is transferred due to free electrons. In conductors the (Q) thermal power crossing the area is given by



$$Q = -k \frac{dT}{dx} \left(\frac{watt}{m^2}\right) \quad \text{—— (1)}$$

$$\frac{dT}{dx} = \text{temperature gradient} \left(\frac{{}^\circ kelvin}{m}\right)$$

where k is thermal conductivity $\left(\frac{watt}{{}^\circ k \cdot m}\right)$

for conductors k due to free e⁻s is given by

$$k = \frac{1}{3} \frac{n \pi^2 K^2 T \tau_c}{m} \quad \text{—— (2)}$$

for conductors $\sigma = \frac{n q^2 \tau_c}{m}$ —— (3)

$$\frac{(2)}{(3)} \quad \frac{k}{\sigma} = \frac{\frac{1}{3} \cancel{n} \pi^2 K^2 T \cancel{\tau_c} / \cancel{m}}{\cancel{n} q^2 \cancel{\tau_c} / \cancel{m}}$$

$$\frac{k}{\sigma T} = \frac{1}{3}\frac{\pi^2 k^2}{q^2}$$ | K is Boltzmann constant, q is charge of electron

after substituting values we get

$$\boxed{\begin{gathered}\frac{k}{\sigma T} = 2.45 \times 10^{-8} \\ \frac{k}{\sigma T} = L\end{gathered}} \quad \text{--- (4)}$$

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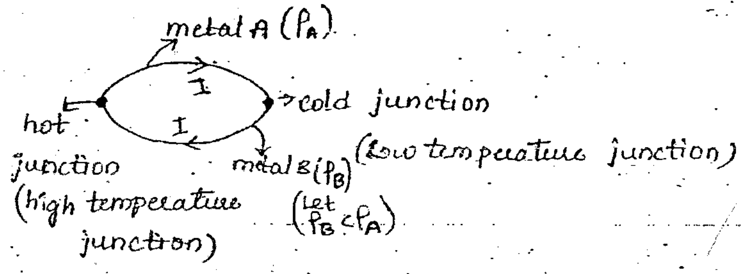
$L = 2.45 \times 10^{-8}$ = Lorentz number.

Eqⁿ (4) is called as weidemann Franz law of conductors, which says the ratio of thermal conductivity (k) and electrical conduct. (σ) at any temperature (T) is constant

** Thermoelectric Effects:

** Seebeck effect:-



If two dissimilar metals (A, B) having different resistivities are joined. If one end is maintained at high temperature, other is maintained at low temperature then electromotive force (emf) is produced. This emf makes the current flow in the loop. This is called as seebeck effect. ⇒ Seebeck invented thermocoupl

** Peltier Effect:- (converse of seebeck effect)

If two dissimilar metals are joined, if current is flown in the loop then one junction goes to high temperature and other junction goes to low temperature. This is called peltier effect. Peltier effect is used in refrigerator.

Types of Conductors:

**) Low resistivity conductors:

These are used in transmission and distribution of electrical current. Ex: Copper (Cu), Aluminium (Al).

**2) High resistivity conductors:

These are used in manufacturing resistors, electrical heating devices, thermocouples. These materials must withstand high temperature. They are generally alloys of metals.

Ex: Constantan (60% Cu, 40% Ni)

Nichrome $\begin{bmatrix} 75 \text{ to } 78\% & Ni \\ 20 \text{ to } 30\% & Cr \\ 1.5\% & Mn \\ \text{remaining is} & Fe \end{bmatrix}$

** (3) Low melting point conductors:

Metals having low melting point are used in soldering joints.
Ex: tin, lead (Pb)

→ Soldering materials [Tin(Sn), Lead (Pb)] have low melting point and high electrical conductivity.

**Note:- Tin (Sn): (i) tin is a silvery white (or) shining white colour (ii) conductivity of tin is less (or) poor compared to copper ($\sigma_{Sn} = 0.917 \times 10^7 (\Omega\text{-m})^{-1}$ at 20°C) (iii) tin can be drawn into wires because it is soft and malleable ~~(iv) tin is used in alloys with lead and copper (v) tin is used for fuses and~~ cable sheathing. (vi) tin is corrosion resistant because of formation of oxide layer.

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(Q) A Resistor measures 4Ω at 40°C and 6Ω at 80°C. At 0°C the resistor will measure (a) 1.5Ω (b) 2Ω (c) 3Ω (d) 4Ω

→ $R_T = R_0(1+\alpha\Delta T)$ where R_0 is Resistance at 0°C and $\Delta T = T-0$

at T = 40°C ⇒ $4 = R_0(1+\alpha 40) \rightarrow (2)$
at T = 80°C ⇒ $6 = R_0(1+\alpha 80) \rightarrow (3)$
(2) ÷ (3) ⇒ $\frac{4}{6} = \frac{1+40\alpha}{1+80\alpha} \Rightarrow \alpha = \frac{1}{40} \rightarrow (4)$

put (4) in (2)
$4 = R_0(1+\frac{1}{40}40) \Rightarrow R_0 = 2\Omega$