Unit 6: Work, Power, Energy and Batteries (Q No. 7 and Q. No. 8)

Part A: Work, Power Energy

Resistance Temperature Coefficient

1. With neat sketch & example, show the effect of change in temperature on resistance of: (a)Metal (b) Insulator (c) Semiconductor (d) Common & Special Alloys.

Pure Metals (Conductors): The conductor has more number of free electrons. When such conductor is connected across some voltage, ions get formed inside it and the electrons which are moving randomly will get aligned in certain direction. At low temperature ions are stationery, but as soon as temperature increases, the unmovable ions gain energy and start oscillating about their mean position. More the temperature more will be the magnitude of oscillation. This will cause obstruction to flow of free electrons; which lead to increase in resistance. So in case of conductor, with increase in temperature its resistance will increase. So the conductors have positive temperature coefficient of resistance. Examples: Gold, Silver, Copper etc.

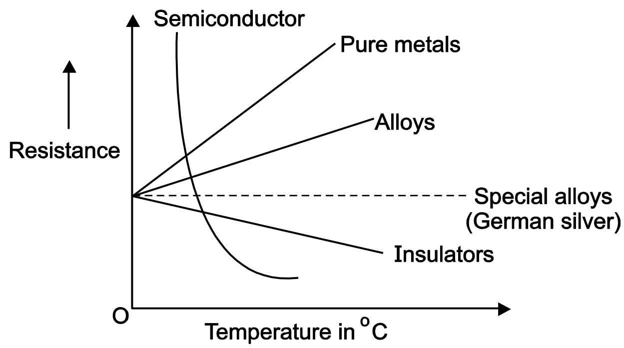

Fig. Variation of Resistance with respect to Temperature

Insulator: In insulator the numbers of free electrons are less. With increase in temperature, vibration of ions will increase. But simultaneously the electrons from the atoms gain extra energy and get escaped from their parent atoms and become available for conduction. This reduces the resistance of insulting material.

So in case of insulator, with increase in temperature, its resistance will decrease. The insulators have negative temperature coefficient of resistance. Examples: Carbon, Mica, Rubber, Plastic etc.

Semiconductor: At low temperature, the resistance of semiconductor is high. But dominant increase in temperature gives additional energy to the electrons available in valency band.

These electrons cross over the narrow energy gap and enters into conduction band. So in case of semiconductor, after certain rise in temperature the resistance drastically reduces to small value and remains constant thereafter

Examples: Silicon, Germenium.

Alloy: The resistance of common alloys such as bronze, brass, steel increases as the temperature increases, but the rate of increase is very small. In special alloys an increase in temperature not only causes an obstruction to the electron movement but also compensates for this by increase in number of free electrons where the number of free electrons is about equal to the obstruction to the thermal energy gained. The temperature change may have very little effect on resistance. e.g. Manganin, Eureka show almost no change in resistance with change in temperature. So such types of alloys are used to make resistance boxes.

2. Define Resistance Temperature Coefficient (RTC) and state the factors on which RTC depends.

RTC is defined as the change in resistance per ohm initial resistance per degree change in temperature.

$$\alpha_o = \frac{R_t - R_o}{R_o t}$$

Unit of RTC $\frac{\text{Ohm}}{\text{Ohm}^{o}\text{C}} = \frac{\mathbf{1}}{\mathbf{{}^{o}C}}$ **or / ºC per degree Celsius**

Factors affecting RTC

1) **Type and nature of material:**

   Conductors, general alloys will have positive temperature coefficient

   Insulators and semiconductors will have negative temperature coefficient

   Special alloys, E.g. Eureka, Manganin will have zero temperature coefficient

2) **Temperature:** Change in temperature changes RTC

3. With usual notations derive the expression, $\alpha_2 = \alpha_1 / (1 + \alpha_1 (t_2 - t_1))$.

Let us consider a conducting material whose initial resistance is $\mathbf{R_1}$ at temperature $\mathbf{t_1}$**ºC** i.e. at point A

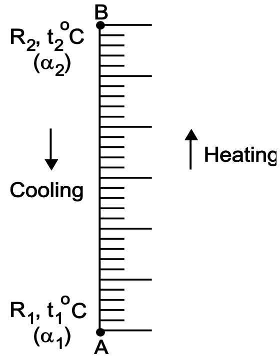

Fig.

Now, if the temperature of heating of the material is gradually increased by heating process up to temperature **t_2°C** i.e. at point B, then it's resistance will be **R_2**

The expression for R_2 ,

$$R_2 = R_1 \left[1 + \alpha_1 \cdot (t_2 - t_1)\right] \qquad \ldots (1)$$

Where α_1 is T.C.R. at t_1°C

Now consider that, the material is having resistance R_2 at t_2°C and if the temperature of conducting material is gradually reduced by cooling process up to initial temperature t_1°C i.e. up to point A,

The expression for R_1 ,

$$R_1 = R_2 \left[1 + \alpha_2 \cdot (t_1 - t_2)\right] \qquad \ldots (2)$$

where α_2 is T.C.R. at t_2°C.

From equation (1) and (2), taking ratio of

$$\frac{R_1}{R_2} = 1 + \alpha_2 \, (t_1 - t_2) \qquad \ldots (3)$$

$$= \frac{1}{1 + \alpha_1 (t_2 - t_1)} \qquad \ldots (4)$$

From equation (3) and (4)

$$\alpha_2 \, (t_1 - t_2) = \frac{1}{1 + \alpha_1 \, (t_2 - t_1)} - 1$$

$$= \frac{1 - 1 - \alpha_1 \, (t_2 - t_1)}{1 + \alpha_1 \, (t_2 - t_1)} = \frac{-\alpha_1 \, (t_2 - t_1)}{1 + \alpha_1 \, (t_2 - t_1)}$$

Multiplying both sides by negative sign and rearranging the equation.

$$\alpha_2 (t_2 - t_1) = \frac{\alpha_1 (t_2 - t_1)}{1 + \alpha_1 (t_2 - t_1)}$$

$$\boldsymbol{\alpha_2 = \frac{\alpha_1}{1 + \alpha_1 (t_2 - t_1)}} \qquad \text{---- (5)}$$

If we consider

$t_1 = 0^oC$ and $t_2 = t^o\ C, \alpha_1 = \alpha_o$ and $\alpha_2 = \alpha_t$ then,

$$\alpha_t = \frac{\alpha_0}{1 + \alpha_0 t}$$

From equation (5)

$$\alpha_2 + \alpha_1\, \alpha_2 \cdot (t_2 - t_1) = \alpha_1$$

$$\boxed{\alpha_1 - \alpha_2 = \alpha_1\, \alpha_2\, (t_2 - t_1)}$$

Insulation Resistance

4. What is insulation resistance? State the factors affecting value of Insulation resistance.

The **insulation resistance** is defined as the resistance offered by an insulating material to the flow of leakage current.

It is denoted by R_i and its unit is Ω.

Mathematically, it is defined as, $R_i = V/I_l$

Where, V = Voltage measured between conductor and earth

I_l = Leakage current and R_i = Insulation resistance.

Factors affecting value of Insulation Resistance

1) Resistivity of the material: Ri depends on type and nature (resistivity) of the material

2) Temperature: As temperature of insulating material increases Ri decreases and vice versa

3) Length: Ri is inversely proportional to the length of the cable

4) Moisture: Ri decreases when the moisture content in insulating material increases.

5. Derive an expression for insulation resistance of a single core cable.

To find the resistance offered by insulating material (R_i) of a single core cable having length '*l*' meters to flow of leakage current, cross section of the cable is considered as shown in figure.

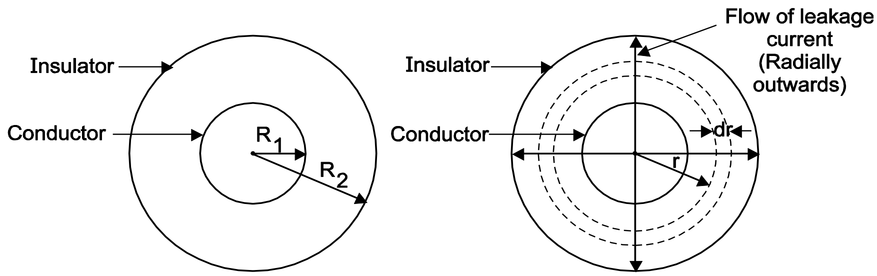

Fig.

Due to finite insulation resistance of the insulating material used, some leakage current flows from the conductor in radialy outward direction. Therefore, to obtain the expression for R_i, a small section with thickness as "*dr*" at a distance of "*r*" meters from the centre of the cable is considered.

Where, R_1 = Radius of conductor, R_2 = Radius of cable including conductor and insulator

Length offered by insulation layer = *dr*, Cross-sectional area = $2\pi rl$

The resistance offered by small section is

$$dR_i = \rho \times \frac{dr}{2\pi rl}$$

The total insulation resistance R_i can be obtained by integrating "dR_i" over the entire radius of insulating material i.e. from R_1 and R_2.

$$R_i = \int_{R_1}^{R_2} dR_i = \int_{R_1}^{R_2} \frac{\rho\, dr}{2\pi rl} = \frac{\rho}{2\pi l}\int_{R_1}^{R_2} \frac{dr}{r} = \frac{\rho}{2\pi l}\left[\log_e r\right]_{R_1}^{R_2}$$

$$R_i = \frac{\rho}{2\pi l}\left[\log_e R_2 - \log_e R_1\right] = \frac{\rho}{2\pi l}\, l_n\left(\frac{R_2}{R_1}\right)\ \Omega$$

$$\boxed{\mathbf{R_i = \frac{\rho}{2\pi l}\log_e\left[\frac{R_2}{R_1}\right]}}\quad \Omega$$

Questions asked in End-Sem Dec 2019 Examination

Q. Define temperature coefficient of resistance. State the factors on which it depends. [4 M] (Refer Q. No.2)

Q. What Prove that $\alpha_2 = \alpha_1/(1 + \alpha_1 (t_2 - t_1))$, all the symbols have their appropriate meaning. [6M] (Refer Q. No. 03)