CURRENT ELECTRICITY

TEMPERATURE DEPENDENCE OF RESISTIVITY

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The resistivity of a material is found to be dependent on the temperature. Different materials do not exhibit the same dependence on temperatures. Over a limited range of temperatures, that is not too large, the resistivity of a metallic conductor is approximately given by,

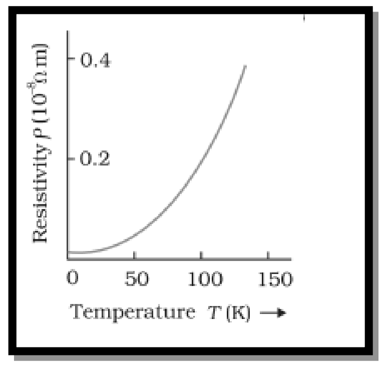
$$\rho_T = \rho_0[1 + \alpha(T - T_0)]$$

Where ρ_T is the resistivity at a temperature T and ρ_0 is the same at a reference temperature T_0. α is called the temperature co-efficient of resistivity, and from, the dimension of α is (Temperature)–1

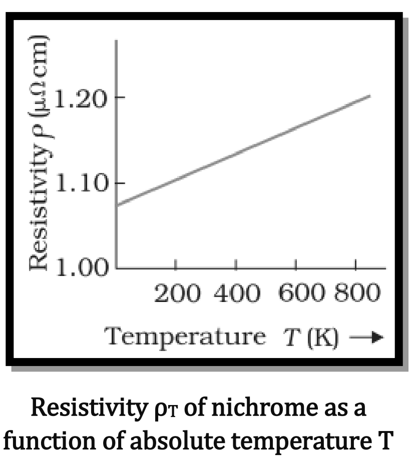
For metals, α is positive and values of α for some metals at T0 = 0°C are

The relation of implies that a graph of ρ_T plotted against T would be a straight line. At temperatures much lower than 0°C, the graph, however, deviates considerably from a straight line.

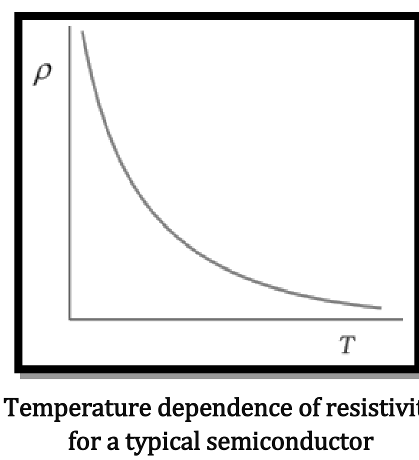
Thus, can be used approximately over a limited range of T around any reference temperature T0, where the graph can be approximated as a straight line.



Resistivity ρ_T of copper as a function of temperature T.



Resistivity ρ_T of nichrome as a function of absolute temperature T



Temperature dependence of resistivity for a typical semiconductor

Some materials like Nichrome (which is an alloy of nickel, iron and chromium) exhibit a very weak dependence of resistivity with temperature. Manganin and constantan have similar properties. These materials are thus widely used in wire bound standard resistors since their resistance values would change very little with temperatures.
Unlike metals, the resistivities of semiconductors decrease with increasing temperatures.

We can qualitatively understand the temperature dependence of resistivity, in the light of our derivation of from this equation, resistivity of a material is given by

$$\rho = \frac{1}{\sigma} = \frac{m}{ne^2 r}$$

ρ thus depends inversely both on the number n of free electrons per unit volume and on the average time τ between collisions. As we increase temperature, average speed of the electrons, which act as the carriers of current, increases resulting in more frequent collisions. The average time of collisions τ, thus decreases with temperature
In a metal, n is not dependent on temperature to any appreciable extent and thus the decrease in the value of τ with rise in temperature causes ρ to increase as we have observed.

For insulators and semiconductors, however, n increases with temperature. This increase more than compensates any decrease in τ in so that for such materials, ρ decreases with temperature.

Example. The resistance of the platinum wire of a platinum resistance thermometer at the ice point is 5 Ω and at steam point is 5.23 Ω. When the thermometer is inserted in a hot bath, the resistance of the platinum wire is 5.795 Ω. Calculate the temperature of the bath.

Solution R0 = 5 Ω, R100 = 5.23 Ω and Rt = 5.795 Ω

$$t = \frac{R_1 - R_0}{R_{100} - R_0} \times 100 \qquad R_1 = R_2\left(1 + at\right)$$

$$= \frac{5.795 - 5}{5.23 - 5} \times 100$$

$$= \frac{0.795}{0.23} \times 100 = 345.65^\circ\text{C}$$

Example An electric toaster uses nichrome for its heating element. When a negligibly small current passes through it, its resistance at room temperature (27.0 °C) is found to be 75.3 Ω. When the toaster is connected to a 230 V supply, the current settles, after a few seconds, to a steady value of 2.68 A. What is the steady temperature of the nichrome element? The temperature coefficient of resistance of nichrome averaged over the temperature range involved, is 1.70×10^{-4} °C^{-1}.

Solution When the current through the element is very small, heating effects can be ignored and the temperature T_1 of the element is the same as room temperature. When the toaster is connected to the supply, its initial current will be slightly higher than its steady value of 2.68 A. But due to heating effect of the current, the temperature will rise. This will cause an increase in resistance and a slight decrease in current. In a few seconds, a steady state will be reached when temperature will rise no further, and both the resistance of the element and the current drawn will achieve steady values. The resistance R_2 at the steady temperature T_2 is

$$R_2 = \frac{230\text{V}}{2.68\text{A}} = 85.8\Omega$$

Using the relation

$$R_2 = R_1 [1 + \alpha (T_2 - T_1)]$$

With $\alpha = 1.70 \times 10^{-4}\ {}^\circ\text{C}^{-1}$, we get

$$T_2 - T_1 = \frac{(85.8 - 75.3)}{(75.3) \times 1.70 \times 10^{-4}} = 820^\circ\text{C}$$

That is, $T_2 = (820 + 27.0)\ {}^\circ\text{C} = 847\ {}^\circ\text{C}$

Thus, the steady temperature of the heating element (when heating effect due to the current equal’s heat loss to the surroundings) is 847 °C.