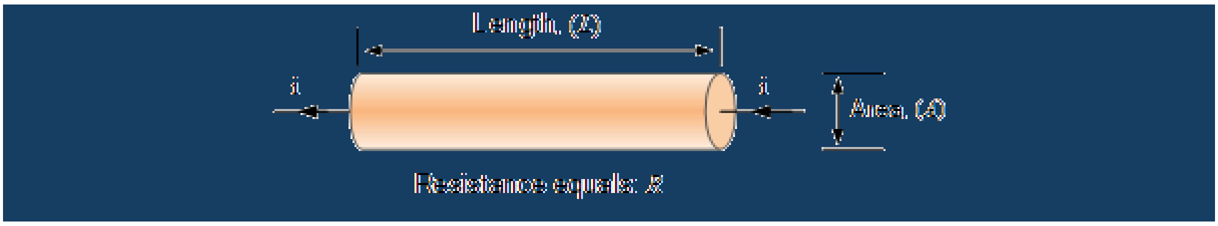


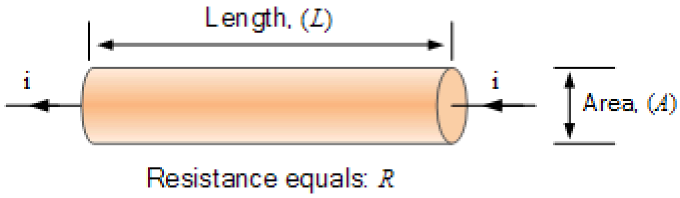
Resistivity

Resistivity of materials is the resistance to the flow of an electric current with some materials resisting the current flow more than others.

Ohms Law states that when a voltage (V) source is applied between two points in a circuit, an electrical current (I) will flow encouraged by the presence of a potential difference between these two points. The amount of electrical current that flows is restricted by the amount of resistance (R) present. In other words, the voltage encourages the current to flow (the movement of charge), but it is resistance that discourages it.

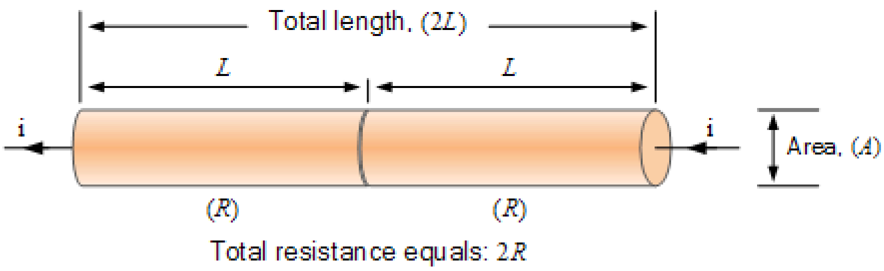
But the electrical resistance between these two points can depend on many factors such as the conductors length, its cross-sectional area, the temperature, as well as the actual material from which it is made. For example, let's assume we have a piece of wire (a conductor) that has a length *L*, a cross-sectional area *A* and a resistance *R* as shown.

A Single Conductor



The electrical resistance, R of this simple conductor is a function of its length, L and the conductors area, A. Ohms law tells us that for a given resistance R, the current flowing through the conductor is proportional to the applied voltage as I = V/R. Now suppose we connect two identical conductors together in a series combination as shown.

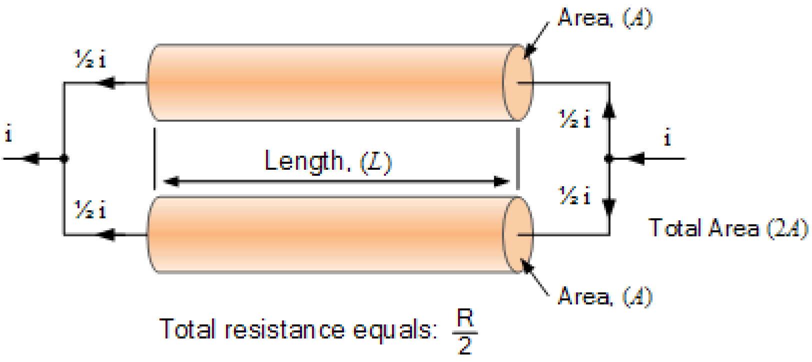
Doubling the Length of a Conductor



Here by connecting the two conductors together in a series, we have effectively doubled the total length of the conductor, 2L while the cross-sectional area, A remains exactly the same. But as well as doubling the length, we have also doubled the total resistance of the conductor, giving 2R. Thus the resistance of the conductor is proportional to its length, that is: **R ∝ L**. In other words, we would expect the electrical resistance of a conductor (or wire) to be proportionally greater the longer it is.

Note also that by doubling the length and therefore the resistance of the conductor (2R), to force the same current, *i* to flow through the conductor as before, we need to double (increase) the applied voltage as now I = (2V)/(2R). Next suppose we connect the two identical conductors together in parallel combination as shown.

Doubling the Area of a Conductor



Here by connecting the two conductors together in a parallel combination, we have effectively doubled the total area giving 2A, while the conductors length, L remains the same as the original single conductor. But as well as doubling the area, by connecting the two conductors together in parallel we have effectively halved the total resistance of the conductor, giving 1/2R as now each half of the current flows through each conductor branch.

Thus the resistance of the conductor is inversely proportional to its area, that is: **R 1/∝ A**, or R ∝ 1/A. In other words, we would expect the electrical resistance of a conductor (or wire) to be proportionally less the greater is its cross-sectional area.

Also by doubling the area and therefore halving the total resistance of the conductor branch (1/2R), for the same current, *i* to flow through the parallel conductor branch as before we only need half (decrease) the applied voltage as now I = (1/2V)/(1/2R).

So hopefully we can see that the resistance of a conductor is directly proportional to the length (L) of the conductor, that is: R ∝ L, and inversely proportional to its area (A), R ∝ 1/A. Thus we can correctly say that resistance is:

Proportionality of Resistance

$$R \propto \frac{L}{A}$$

But as well as length and conductor area, we would also expect the electrical resistance of the conductor to depend upon the actual material from which it is made, because different conductive materials, copper, silver, aluminium, etc all have different physical and electrical properties. Thus we can convert the proportionality sign (∝) of the above equation into an equals sign simply by adding a “proportional constant” into the above equation giving:

Electrical Resistivity Equation

$$R = \rho\left(\frac{L}{A}\right)\ \Omega$$

Where: R is the resistance in ohms (Ω), L is the length in meters (m), A is the area in square meters (m^2), and where the proportional constant ρ (the Greek letter "rho") is known as **Resistivity**.

Resistivity

The electrical resistivity of a particular conductor material is a measure of how strongly the material opposes the flow of electric current through it. This resistivity factor, sometimes called its "specific electrical resistance", enables the resistance of different types of conductors to be compared to one another at a specified temperature according to their physical properties without regards to their lengths or cross-sectional areas. Thus the higher the resistivity value of ρ the more resistance and vice versa.

For example, the resistivity of a good conductor such as copper is on the order of 1.72×10^{-8} ohms per meter (or 17.2 nΩ/m), whereas the resistivity of a poor conductor (insulator) such as air can be well over 1.5×10^{14} or 150 trillion Ω/m.

Materials such as copper and aluminium are known for their low levels of resistivity thus allowing electrical current to easily flow through them making these materials ideal for making electrical wires and cables. Silver and gold have much low resistivity values, but for obvious reasons are more expensive to turn into electrical wires.

Then the factors which affect the resistance (R) of a conductor in ohms can be listed as:

- The resistivity (ρ) of the material from which the conductor is made.
- The total length (L) of the conductor.
- The cross-sectional area (A) of the conductor.
- The temperature of the conductor.

Resistivity Example No1

Calculate the total DC resistance of a 100 meter roll of $2.5mm^2$ copper wire if the resistivity of copper at 20^oC is 1.72×10^{-8} Ω per meter.

Given: resistivity of copper at 20^oC is 1.72×10^{-8}, coil length L = 100m, the cross-sectional area of the conductor is $2.5mm^2$ giving an area of: $A = 2.5 \times 10^{-6}$ $meters^2$.

$$R = \rho \frac{L}{A}\ \Omega$$

$$R = \frac{\left(1.72\times10^{-8}\right)\times100}{2.5\times10^{-6}} = 688m\Omega$$

We said previously that resistivity is the electrical resistance per unit length and per unit of conductor cross-sectional area thus showing that resistivity, ρ has the dimensions of ohms per meter, or Ω.m as it is commonly written. Thus for a particular material at a specified temperature its electrical resistivity is given as.

Electrical Resistivity, Rho

$$\rho = \frac{R\times A}{L} = \frac{\text{ohms}\times\text{meters}^2}{\text{meters}} = \Omega.m$$

Electrical Conductivity

While both the electrical resistance (R) and resistivity (or specific resistance) ρ, are a function of the physical nature of the material being used, and of its physical shape and size expressed by its length (L), and its sectional area (A), **Conductivity**, or specific conductance relates to the ease at which electric current con flow through a material.

Conductance (G) is the reciprocal of resistance (1/R) with the unit of conductance being the siemens (S) and is given the upside down ohms symbol mho, ℧. Thus when a conductor has a conductance of 1 siemens (1S) it has a resistance is 1 ohm (1Ω). So if its resistance is doubled, the conductance halves, and vice-versa as: siemens = 1/ohms, or ohms = 1/siemens.

While a conductors resistance gives the amount of opposition it offers to the flow of electric current, the conductance of a conductor indicates the ease by which it allows electric current to flow. So metals such as copper, aluminium or silver have very large values of conductance meaning that they are good conductors.

Conductivity, σ (Greek letter sigma), is the reciprocal of the resistivity. That is 1/ρ and is measured in siemens per meter (S/m). Since electrical conductivity σ = 1/ρ, the previous expression for electrical resistance, R can be rewritten as:

Electrical Resistance as a Function of Conductivity

$$R = \rho\frac{L}{A} \quad \text{and} \quad \sigma = \frac{1}{\rho}$$

$$\therefore R = \frac{L}{\sigma A}\ \Omega$$

Then we can say that conductivity is the efficiency by which a conductor passes an electric current or signal without resistive loss. Therefore a material or conductor that has a high conductivity will have a low resistivity, and vice versa, since 1 siemens (S) equals $1\Omega^{-1}$. So copper which is a good conductor of electric current, has a conductivity of 58.14 x 10^6 siemens per meter.

Resistivity Example No2

A 20 meter length of cable has a cross-sectional area of $1mm^2$ and a resistance of 5 ohms. Calculate the conductivity of the cable.

Given: DC resistance, R = 5 ohms, cable length, L = 20m, and the cross-sectional area of the conductor is $1mm^2$ giving an area of: A = 1 x 10^{-6} $meters^2$.

$$R = \frac{L}{\sigma A} \qquad \therefore \sigma = \frac{L}{RA}$$

$$\sigma = \frac{L}{RA} = \frac{20}{5\times1\times10^{-6}} = 4MS/m$$

That is 4 mega-siemens per meter length.

Resistivity Summary

We have seen in this tutorial about resistivity, that resistivity is the property of a material or conductor that indicates of well the material conducts electrical current and also that the electrical resistance (R) of a conductor depends not only on the material from which the conductor is made, copper, silver, aluminium, etc. but also on its physical dimensions.

The resistance of a conductor is directly proportional to its length (L) as $R \propto L$. Thus doubling its length will double its resistance, while halving its length would halve its resistance. Also the resistance of a conductor is inversely proportional to its cross-sectional area (A) as $R \propto 1/A$. Thus doubling its cross-sectional area would halve its resistance, while halving its cross-sectional area would double its resistance.

We have also learnt that the resistivity (symbol: ρ) of the conductor (or material) relates to the physical property from which it is made and varies from material to material. For example, the resistivity of copper is generally given as: 1.72 x 10^{-8} Ω.m. The resistivity of a particular material is measured in units of Ohm-Meters (Ω.m) which is also affected by temperature.

Depending upon the electrical resistivity value of a particular material, it can be classified as being either a “conductor”, an “insulator” or a “semiconductor”. Note that semiconductors are materials where its conductivity is dependent upon the impurities added to the material.

Resistivity is also important in power distribution systems as the effectiveness of the earth grounding system for an electrical power and distribution system greatly depends on the resistivity of the earth and soil material at the location of the system ground.

Conduction is the name given to the movement of free electrons in the form of an electric current. Conductivity, σ is the reciprocal of the resistivity. That is $1/\rho$ and has the unit of siemens per metre, S/m. Conductivity ranges from zero (for a perfect insulator) to infinity (for a perfect conductor). Thus a super conductor has infinite conductance and virtually zero ohmic resistance.