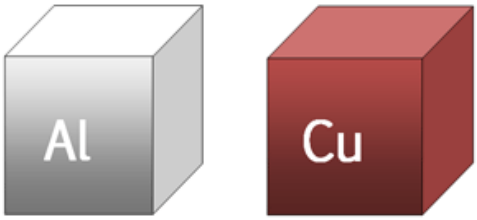
Bulk Properties of Copper: Density and Resistivity

Density and resistivity of materials are called *bulk properties*: their value doesn't depend on the size or shape of a particular sample – only on the material itself.

When we say that copper is a heavier metal than aluminium, we are comparing their *densities*. In a similar way, when we say that copper is a better conductor than aluminium, we are comparing their *resistivities*.

This e-source looks at calculating the density and resistivity of materials, which use similar mathematical methods. Below are different sections, for quick navigation.



Scientists like the letter ρ (Rho). It is used to denote density, resistivity and many other scientific things. It is always used in lower case because the upper case is the same as P.

Density

The two blocks on the right are the same size, but the copper one has a greater mass than the aluminium one. That is because copper has a higher **density** than aluminium. Density is the mass per unit volume of a substance.

Keeping it in proportion

We know that the bigger the volume of the cube, the bigger the mass. Mathematically this can be written like this:

$m \propto V$ (mass is proportional to volume)

To work out the exact mass from the volume we need to know the density, ρ (Greek symbol Rho), and put that in the expression. Density is the mass in kg of 1 m^3 of the material. For copper $\rho = 8940$ (kg m^{-3}). For aluminium $\rho = 2700$ (kg m^{-3}). Aluminium has less than one third the density of copper (making it good for building aircraft).

Now the proportionality can be changed to an equation.

$$m = \rho V$$

The density ρ depends on which substance the cube is made of.

ρ is the constant of proportionality that converts $\propto$ to $=$

Rearranging the equation gives:

$$\rho = m / V$$

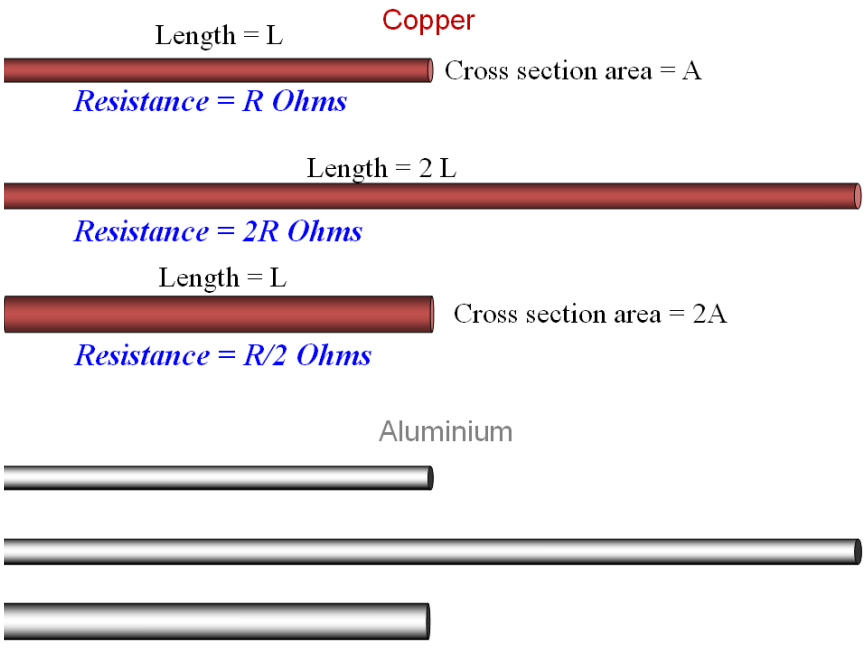
This shows that the units of density are kg / m^3 (or kg m^{-3}).

Resistivity

Calculating resistivity uses the same mathematical approach.

To understand this part you need to know Ohm's Law:

$R = V / I$ (resistance = volts per amp).



Resistivities	
Material	Resistivity ρ (Ω·m)
Insulators	
Teflon	1.0×10^{23}
Quartz	7.5×10^{17}
Rubber	7.5×10^{17}
Glass	7.5×10^{17}
Conductors	
Nichrome alloy	1.6×10^{-6}
Lead	2.2×10^{-7}
Iron	9.7×10^{-8}
Tungsten	9.7×10^{-8}
Aluminium	2.7×10^{-8}
Gold	2.2×10^{-8}
Copper	$\mathbf{1.7 \times 10^{-8}}$
Silver	1.6×10^{-8}
Graphene	1.0×10^{-8}

A Thought Experiment with Copper and Aluminium Wires

If the top wire length L and cross section area A has a resistance R, then there are two things we can say about the next two wires.

The next wire with length 2L will have double the resistance of 2R. This is just like adding two pieces of the top wire in series.

Therefore:

$R \propto L$ (resistance is proportional to length).

The third wire has length L but twice the cross section area, 2A. This is the same as adding two pieces of the top wire in parallel. The resistance will be R/2.

Therefore:

$R \propto 1 / A$ (resistance is inversely proportional to cross section area).

Combining both proportionalities gives:

$$R \propto L / A$$

The same maths works for aluminium, or any conductor, but if we want to work out the actual resistance we need to know how resistive the material is to an electric current. We need to know the **resistivity** of copper and aluminium. Resistivity is a measure of how hard it is to get an electric current to flow in any material. Copper is an excellent conductor, so it has a LOW resistivity.

Adding the resistivity term gives:

$$R = \rho (L / A)$$

ρ is the constant of proportionality again, so $\propto$ becomes $=$

Rearranging gives:

$$\rho = R (A / L)$$

This shows that the units of resistivity are $\Omega \cdot m$ (ohm·metre). However, don't panic! You do not need to understand the unit. Provided you use the unit ohm metre as the unit of resistivity, metre as the unit for length and metre^2 as the unit of area, the resistivity equation will give an answer for the resistance in ohm.

Turning resistivity upside down

Resistivity is a measure of how bad a conductor is. If you look at the table you will see that materials with high resistivity are *insulators*. The opposite of resistivity is conductivity. This is given the letter sigma and is the reciprocal of resistivity:

Electrical conductivity, $\sigma = 1/\rho$

Questions and Activities

1. **If you have two identical saucepans, one made of copper and the other of aluminium, how many times heavier will the copper one be?**

2. **Compare the resistivities of silver and nichrome alloy. How many times better is silver than nichrome at conducting electricity?**

3. **Calculate the resistance of a copper cable 50 mm in diameter and 30 km long.**

4. **If you had to replace the cable in Question 3 with aluminium, what would the diameter need to be to have the same resistance?**

5. **The unit of conductivity is the Siemens m^{-1}. Find out who Siemens was and where you will find his name today.**

Click here for answers

Copper Development Association is a non-profit organisation that provides information on copper's properties and applications, its essentiality for health, quality of life and its role in technology. It supports education through a collection of resources spanning biology, chemistry and physics. These materials have been developed in conjunction with the Association for Science Education, and reviewed by teachers.

For more resources, visit www.copperalliance.org.uk/education.