# Resistance

By way of review — electric current is made possible by the fact that the outer-shell electrons of some atoms are not tightly bound to the nucleus.

With a little nudge, in the form of electromotive force (which we'll call voltage from now on) they can be encouraged to become vagabonds, hop-scotching from atom to atom along a linear path through a conductor, from negative to positive.

We already know that atoms can differ in the number of orbital electron shells they have, and the number of electrons in their outmost shell. We also know that it's the outer shell electrons that participate in current flow.

But here’s a new wrinkle: not all so-called “free electrons” are equally free.

The atoms of all materials will naturally resist forces that are attempting to disturb their state of equilibrium. That natural *resistance* to current flow varies from one material to another.

In some materials, sliver for example, the nucleus doesn’t have much of a hold on the outer shell electrons. So current flow is easily produced.

In other substances, the outer shell electrons are more tightly bound, so it takes proportionately more force to produce a flow of current through those materials.

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Resistance is not necessarily a bad thing.

On the negative side, there is the example of Thomas Edison’s early efforts to electrify Detroit. He was a staunch proponent of direct current, and built generating plants that provided 120-volt DC power.

Unfortunately, because of the resistance of the wiring, he wasn't able to provide service to anyone further than a mile from the nearest generating plant.

Resistance also produces inefficiencies.

Atoms do not willingly make free electrons available for current flow. When we force them to do that, we get two things: current flow, and energy released in the form of heat. The heat is not usually useful and can even become highly detrimental. It's usually just an engineering nuisance; derivative energy that must somehow be dissipated — as with your computer's heat sinks and fans.

On the other hand, resistance is a very handy phenomenon in electronics, and is exploited in all sorts of useful ways.

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Okay — enough of the theoretical stuff for a while. Now we're going to start learning some things that are way more interesting and fun — practical stuff!

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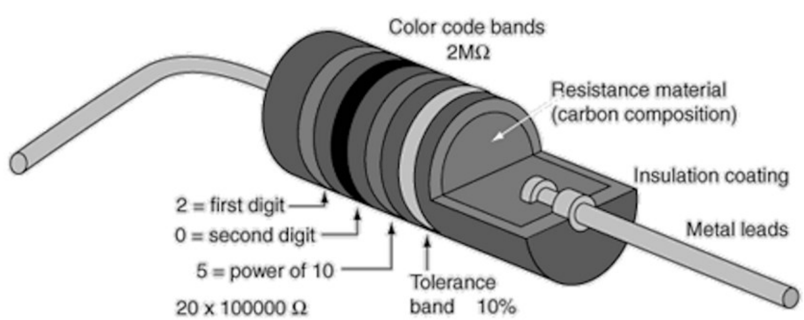
You've probably already heard about *resistors*, because resistors are the most common component in electronics.

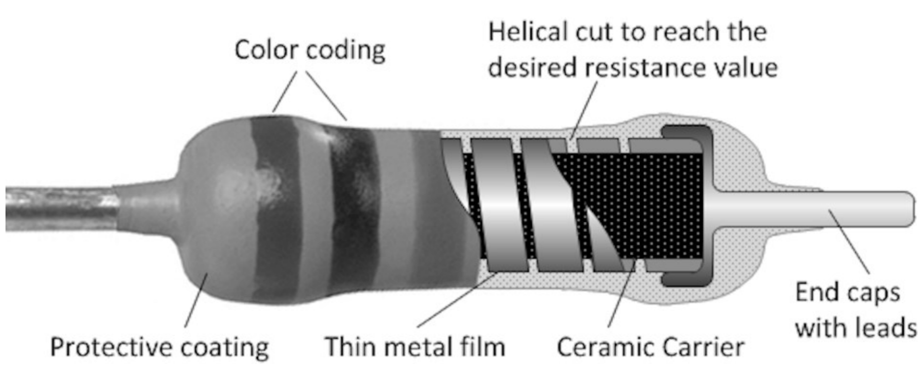
As you have probably already guessed, the function of resistors is to resist current flow. But, more accurately, they provide a specific and known amount of resistance. They come in a wide variety of sizes, covering a range from practically zero resistance, to near infinite resistance.

Here's what they look like:



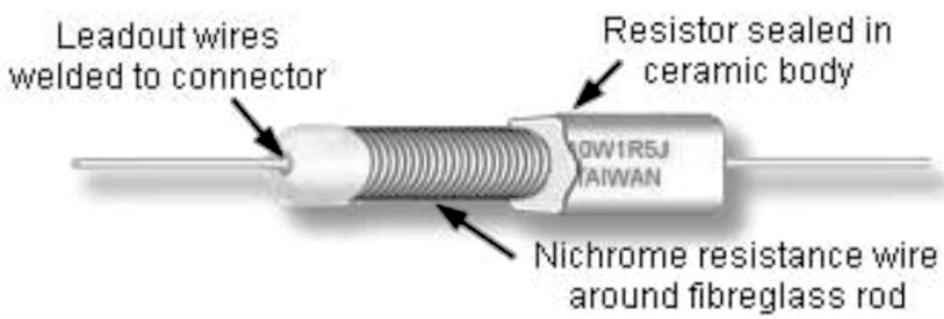

This is a common old carbon composition resistor. These were made by encapsulating a core of powdered carbon, and ceramic material within a phenolic casing. The resistance was determined by the amount of carbon added to the filler. The exact value was difficult to control, so these were offered with *tolerances* of 20%, 10% and 5%, meaning that the initial resistance at room temperature might actually vary within those ranges. This type of resistor also had a rather high *temperature coefficient*, meaning that its resistance value was apt to change significantly with temperature. Various sizes were offered to accommodate the *power dissipation* requirements of particular applications; from 1/8-watt to 5-watts.

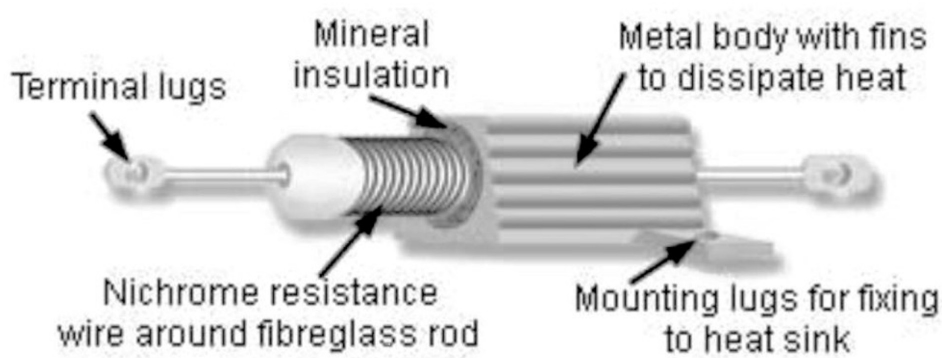
This method of making resistors served for many years during the mid-20th century, but has since been replaced by film types.



These resistors are made by coating a ceramic rod with carbon or metal film. These were originally offered as low tolerance/low temperature coefficient “precision resistors.” Over the years the manufacturing process steadily improved to the point where today these have replaced the carbon composition type, and are commonly available as a low-priced 2% tolerance component.

An older style that is still in use is the *wire-wound* resistor.



Today’s wire-wound resistors are usually used where the power dissipation requirement will be high. They’re made by wrapping resistance wire around a ceramic core, and encapsulating that in a ceramic case. Their power dissipation capabilities are increased by assembling that within a metal casing that serves as a chassis-mounted heat sink.

The unit of resistance is the *ohm*. From the previous lessons, you know where that name probably came from. If you guessed the Bavarian teacher and physicist Georg Ohm, you are right!

The omega symbol, Ω, is often used instead of the word “ohms” — for example, “100Ω” means the same thing as “100-Ohms”.

An ohm is the amount of resistance that will permit an electromotive force of one volt to produce a current of one amp.

Watch out! Here comes some math — in the form of “Ohm’s Law”:

$$R = \frac{E}{I}$$

… where:

- $R$ = ohms
- $E$ = volts (as in <u>e</u>lectromotive force)
- $I$ = current in amps (“<u>i</u>ntensité de courant” — French, coined by Monsieur Ampère)

This says that an unknown resistance $R$ can be determined by dividing the voltage $E$ by the current $I$. By substituting values of 1-volt and 1-amp, you can see that this complies with the definition of an ohm.

By a little algebraic manipulation, this same expression can be used to determine the voltage in a circuit where the current and resistance is known:

$$IR = \frac{\cancel{I}E}{\cancel{I}} \quad \therefore E = IR$$

Multiplying both sides of the equation by *I*, the *I*s on the right cancel each other out, leaving *IR*=*E*.

On the other hand, to find the current in a circuit when the voltage and resistance are known:

$$\frac{R}{E}=\frac{\cancel{E}}{\cancel{E}I} \qquad \therefore \frac{R}{E}=\frac{1}{I} \qquad \therefore I=\frac{E}{R}$$

In this case, dividing both sides of the equation by *E*, the *E*s on the right side cancel each other out, leaving a numerator of "1", and inverting the terms leaves *I*=*E*/*R*.

(Remember? The little "∴" is just a shorthand form of the word "therefore".)

Yes, you can simply invert both sides of the equation. If you question that, you can do it the hard way …

$$\frac{R}{E}=\frac{1}{I}$$

- multiply both sides by *I*
- multiply both sides by *E*

- divide both sides by *R*

After canceling out the like terms in the numerators and denominators, you'll be left with the same thing as if you'd simply inverted both sides.

So much for your first "real life" algebra lesson!

I mentioned that resistors come in various sizes to accommodate different *power dissipation* requirements. You didn't notice that that was not explained?

Let's talk about that …

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