PhyzGuide: Resistance

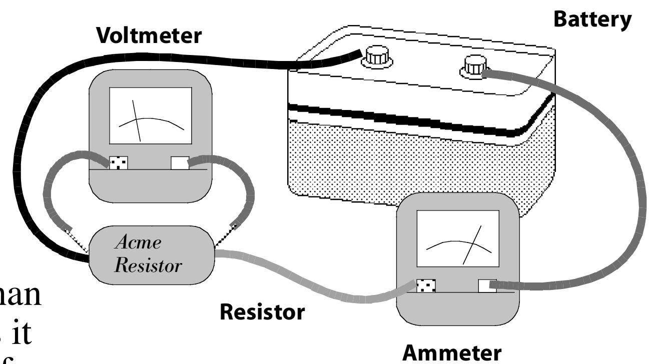
RESISTANCE PLAIN AND SIMPLE

The electrical **resistance** of a wire (or any "standard" conductor) is a measure of how much that object opposes the passage of electric current. This measure is quantified in the following relation.

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

R is the electrical resistance of the conductor
V is the applied voltage or potential difference across the conductor
I is the current induced through the conductor

Experimentally, this value can be found by measuring the current *I* that passes through a resistor when a voltage *V* is applied. Units of resistance are volts per ampere (V/A) and are abbreviated as ohms (Ω).



If a 6 volt potential induces a current of 2 amperes, the conductor has a resistance of 3 ohms.

LOOKING DEEPER

Why does a copper wire have less resistance than an otherwise equivalent iron wire? And why is it that all copper wires don't have equal values of resistance? The resistance of an object is determined by three characteristics of the object.

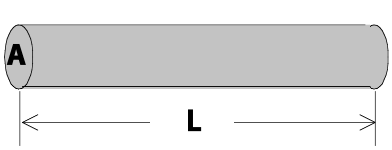
1. Length. A short wire has a lower resistance than a long one*. Resistance is directly proportional to the length of the path through which current flows: $R \propto L$.

2. Cross-sectional Area. A thick wire (with a large cross-sectional area) has a lower resistance than a thin one* (with a small cross-sectional area). Resistance is inversely proportional to cross-sectional area: $R \propto 1/A$.

3. Resistivity. A silver wire has a lower resistance than a lead wire*. Resistivity is a characteristic of a substance (like density) and can be found in tables like the one below. It is denoted by the lowercase Greek letter rho (ρ) and is measured in units of ohm-meters (Ω·m). Resistance is directly proportional to resistivity: $R \propto \rho$.

Together, these proportionalities determine resistance by the following relation.

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



RESISTIVITIES OF VARIOUS SUBSTANCES

Conductors	*ρ (Ω·m)*	*Semiconductors*	*ρ (Ω·m)*
Silver	**1.47×10^{-8}**	**Carbon**	**0.000035**
Copper	**1.72×10^{-8}**	**Germanium**	**0.60**
Aluminum	**2.63×10^{-8}**	**Silicon**	**2300**
Tungsten	**5.51×10^{-8}**	*Insulators*	
Iron	**9.71×10^{-8}**	**Wood**	**$10^{8} - 10^{11}$**
Lead	**22×10^{-8}**	**Rubber**	**$10^{10} - 10^{14}$**
Manganin	**44×10^{-8}**	**Glass**	**$10^{13} - 10^{15}$**
Nichrome	**100×10^{-8}**	**Plastic (lucite)**	**$>10^{13}$**

*all other factors being equal

BUT WAIT! THERE'S MORE...

The resistance of an object depends on its length, cross-sectional area, and the resistivity of the substance from which it was made. But a funny thing happens when the temperature changes. If a metal object is heated, its resistance goes up. If an object made of semiconducting material is heated, its resistance goes down. (Technically, it is the *resistivity* of the substances that increases or decreases—we will deal only with the resulting change in *resistance*.)

To quantify this odd behavior, we use the following relation. If an object has a resistance R_0 at a given temperature, its resistance R at a different temperature is

$$R = R_0(1 + \alpha\Delta T)$$

R is the resistance at the new temperature
R_0 is the resistance at the old temperature
α is the temperature coefficient of resistivity
T is the change in temperature

The **temperature coefficient of resistivity** is a characteristic of a substance (as is resistivity itself). It is denoted by the lowercase Greek letter alpha (α) and has units of 1/°C (or, equivalently, 1/K). Specific values of the temperature coefficient of resistivity can be found in tables like the one below.

WHY?

Why does the resistivity of a metal vary with temperature? Why does a metal resist the flow of charge at all? When electrons travel in a wire, they collide with the relatively heavy metal ions (nuclei and bound electrons). These collisions cause the ions to jiggle more. Faster jiggling means higher temperature. As other electrons try to move through the wire, they are impeded to a greater extent by these faster-jiggling ions. There are therefore more collisions and a further increase in temperature. Semiconductors conduct current by a different mechanism; one that does not involve the free electrons present in metals. For further details, you will have to study semiconductors: the materials at the heart of solid state electronics (diodes, transistors, etc.).

TEMPERATURE COEFFICIENTS OF RESISTIVITY FOR VARIOUS SUBSTANCES

Conductors	*α (1/°C)*
Manganin	**0.0000**
Nichrome	**0.0004**
Platinum	**0.0036**
Silver	**0.0038**
Aluminum	**0.0039**
Copper	**0.0039**
Lead	**0.0043**
Tungsten	**0.0045**
Iron	**0.0065**
Semiconductors	*α (1/°C)*
Carbon	**–0.0005**
Germanium	**–0.05**
Silicon	**–0.07**

HOW WILL IT MAKE ME RICH?

The dependence of resistance on temperature is used to measure temperatures when ordinary "thermal expansion"-based devices cannot be used. The *thermister* is such a device.

DO NOT OPERATE IN DIRECT SUNLIGHT

The warning above appears on some portable tape players and radios. These devices contain many silicon-based electrical components in their circuitry. Look up the temperature coefficient of resistivity for silicon and ponder the significance of the warning: what would happen if the device was operated in direct sunlight?