Electric Resistance

Discussion

introduction

Yech! What a mess this is.

Conduction: S. Gray, 1729 — Resistance: Georg Simon Ohm, 1827.

Regular version…

$$I \propto V$$

$$I = \frac{V}{R} \quad \Rightarrow \quad V = IR \quad \Rightarrow \quad R = \frac{V}{I}$$

Variableogy…

- quantity: resistance R
  unit: ohm [Ω] Georg Ohm (1787–1854) Germany

Fancy version (the magnetohydrodynamic version?)…

$$\mathbf{J} \propto \mathbf{E}$$

$$\mathbf{J} = \sigma\mathbf{E} \quad \Leftarrow \quad \varrho = \frac{1}{\sigma} \quad \Rightarrow \quad \mathbf{E} = \varrho\mathbf{J}$$

Welcome to symbol hell…

Electrical properties

quantity	symbol	unit	symbol	property of…
resistance	R	ohm	Ω	objects
conductance	G	siemens	S	
resistivity	ϱ	ohm meter	Ωm	materials
conductivity	σ	siemens per meter	S/m	

Ohm's law isn't a serious law. It's the jaywalking of physics. Sensible materials and devices obey it, but there are plenty of rogues out there that don't.

resistors

Bad Booze Rots Our Young Guts But Vodka Goes Well.

Better Build Roof Over Your Garage Before Van Gets Wet.

Marking codes for resistors and capacitors

color	example	numeral	multiplier	tolerance	tcr (10^{-6}/K)
none				±20%	
pink			10^{-3}		
silver			10^{-2}	±10%	
gold			10^{-1}	±5%	
black		0	10^{0}		±250
brown		1	10^{1}	±1%	±100
red		2	10^{2}	±2%	±50
orange		3	10^{3}	±0.05%	±15
yellow		4	10^{4}	±0.02%	±25
green		5	10^{5}	±0.50%	±20
blue		6	10^{6}	±0.25%	±10
violet		7		±0.10%	±5
gray		8		±0.01%	±1
white		9			

Source: IEC 60062:2016

materials

Resistance and resistivity. Factors affecting resistance in a conducting wire.

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

Conductors vs. insulators

Best electrical conductors: silver, copper, gold, aluminum, calcium, beryllium, tungsten

Resistivity and conductivity are reciprocals.

Conductivity in metals is a statistical/thermodynamic quantity.

Resistivity is determined by the scattering of electrons. The more scattering, the higher the resistance.

$$\sigma = \frac{ne^2\ell}{m_e v_{rms}}$$

where…

σ = electrical conductivity [S/m]
n = density of free electrons [e/m^3]
e = charge of an electron (1.60×10^{-19} C)
m_e = mass of an electron (9.11×10^{-31} kg)
v_{rms} = root-mean-square speed of electrons [m/s]
ℓ = mean free path length [m]

Graphite

Where does this idea belong? Nichrome was invented in 1906, which made electric toasters possible.

Conducting polymers.

Resistivity of selected materials (~300 K)
(Note the difference in units between metals and nonmetals.)

metals	ρ (nΩ m)	nonmetals	ρ (Ω m)
aluminum	26.5	aluminum oxide (14 °C)	1×10^{14}
brass	64	aluminum oxide (300 °C)	3×10^{11}
chromium	126	aluminum oxide (800 °C)	4×10^{6}
copper	17.1	carbon, amorphous	0.35
gold	22.1	carbon, diamond	2.7
iron	96.1	carbon, graphite	650×10^{-9}
lead	208	germanium	0.46
lithium	92.8	pyrex 7740	40,000
mercury (0 °C)	941	quartz	75×10^{16}
manganese	1440	silicon	640
nichrome	1500	silicon dioxide (20 °C)	1×10^{13}
nickel	69.3	silicon dioxide (600 °C)	70,000
palladium	105.4	silicon dioxide (1300 °C)	0.004
platinum	105	water, liquid (0 °C)	861,900
plutonium	1414	water, liquid (25 °C)	181,800
silver	15.9	water, liquid (100 °C)	12,740
solder	150		
steel, plain	180		
steel, stainless	720		
tantalum	131		
tin (0 °C)	115		
titanium (0 °C)	390		
tungsten	52.8		
uranium (0 °C)	280		
zinc	59		

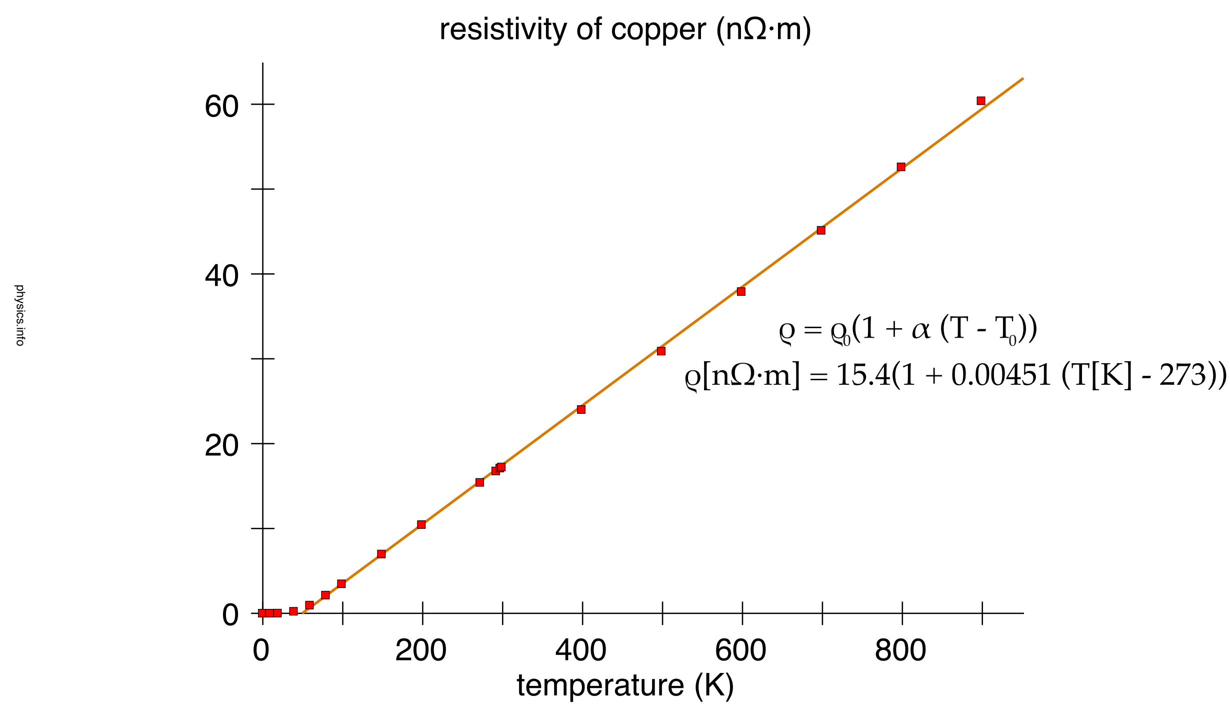
temperature

The general rule is resistivity increases with increasing temperature in conductors and decreases with increasing temperature in insulators. Unfortunately there is no simple mathematical function to describe these relationships.

The temperature dependence of resistivity (or its reciprocal, conductivity) can only be understood with quantum mechanics. In the same way that matter is an assembly of microscopic particles called atoms and a beam of light is a stream of microscopic particles called photons, thermal vibrations in a solid are a swarm of microscopic particles called phonons. The electrons are trying to drift toward the positive terminal of the battery, but the phonons keep crashing into them. The random direction of these collisions disturbs the attempted organized motion of the electrons against the electric field. The deflection or scattering of electrons with phonons is one source of resistance. As temperature rises, the number of phonons increases and with it the likelihood that the electrons and phonons will collide. Thus when temperature goes up, resistance goes up.

For some materials, resistivity is a linear function of temperature.

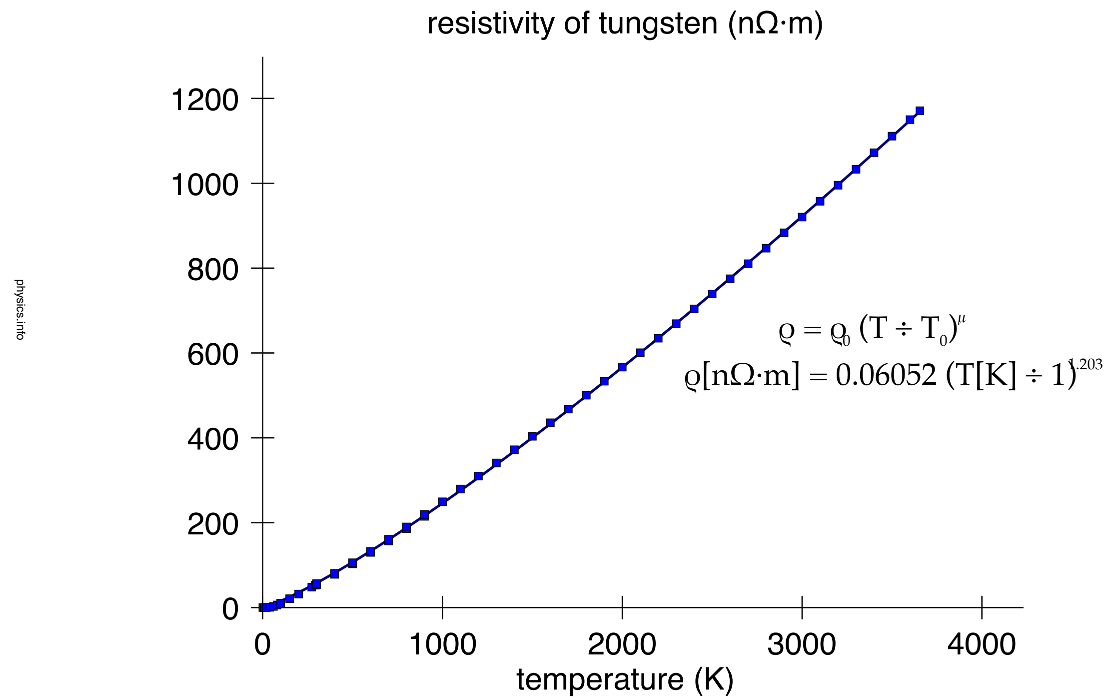
$$\varrho = \varrho_0(1 + \alpha(T - T_0))$$



The resistivity of a conductor increases with temperature. In the case of copper, the relationship between resistivity and temperature is approximately linear over a wide range of temperatures.

For other materials, a power relationship works better.

$$\varrho = \varrho_0(T/T_0)^\mu$$



The resistivity of a conductor increases with temperature. In the case of tungsten, the relationship between resistivity and temperature is best described by a power relationship.

see also: superconductivity

miscellaneous

magnetoresistance

photoconductivity

liquids

electrolytes

gases

dielectric breakdown

plasmas

microphones

A carbon microphone is a backward nothing