V
RESISTANCE

Unless you're using a superconductor, the conductor that current is flowing through will have some kind of resistance. Devices that consume power will have resistance, too. Resistance is simply the opposition to current flow, and is measured in Ohms (Ω). How resistive a conductor is depends on the material that it is made of, and the ambient temperature. In hot weather, power lines have more resistance, for instance. This is why climate change can have compounding unfortunate factors: during hotter days, people might blast their A/Cs more while power lines simultaneously have reduced capacity to carry current to power those A/Cs. The resistivity of common metals is seen in Table 1 when the ambient temperature is assumed to be 68°F (20°C).

Table 1 Resistivity of select metals

Metal	**Resistivity** (ρ)
Silver (Ag)	$1.59 \cdot 10^{-8} \quad \Omega \cdot m$
Copper (Cu)	$1.68 \cdot 10^{-8} \quad \Omega \cdot m$
Aluminum (Al)	$2.65 \cdot 10^{-8} \quad \Omega \cdot m$
Iron (Fe)	$9.71 \cdot 10^{-8} \quad \Omega \cdot m$

"Resistivity," ρ, is actually in units of *Ohm-meters* and is a characteristic of a material. We generally know the length and size (cross-sectional area) of a power line or conductor, and thus it's more likely that we'll want to talk about *resistance*, the total opposition to current flow. Resistance, which only exists in a conductor if current is flowing, has units Ohms (Ω). Resistance is related to the resistivity multiplied by the length of the conductor, divided by the cross-sectional area of the conductor. As a conductor grows longer, the resistance increases, as the electrons have to transfer energy across a farther distance. As the conductor grows fatter, the resistance decreases as there's more space for electrons to flow. There are diminishing returns with this (related to something called the "skin effect") that I won't cover here, though.

Resistance (R) and Resistivity (ρ). These two are related via:

$$R = \frac{\rho \cdot l}{A} \tag{4}$$

where l is the length of the conductor and A is the cross-sectional area of the conductor. The resistivity ρ is material and temperature dependent.

FIG. viii A section of a copper conductor from a distribution line. Donated from linemen who were repairing the lines in my backyard after a blackout caused by high winds. Note the “stranded” nature of the conductor - rather than a solid piece of copper, many smaller, bundled conductors help improve the flexibility of the conductor and can carry more current.

In your house, most of the wiring is copper (unless you are ∼fancy∼ and have silver wiring everywhere). The biggest wires in your house, which are maybe 100-400 amps and carry power in from the utility before they branch off into smaller wires, can sometimes be aluminum. As of writing this (Thursday, October 26, year of our lord 2023), copper is $7,938.90/ton. Aluminum, on the other hand, is $2,197.35/ton. Copper and aluminum have relatively similar resistivity, as shown in Table 1, thus, for larger conductors like transmission lines (carrying possibly thousands of amps), aluminum is used instead for cost and weight-related reasons, as copper is around 3 times as heavy. These large lines sometimes also have a steel core to provide more structural integrity to the overall conductor.

Insulation. The conductor shown in Fig. viii, which is from a distribution line, has an outer casing. Power lines are subject to all kinds of external threats - including high winds which blow them into things like trees, potentially causing fires. You may also notice another ring of metal in between the copper strands, the insulator, and the outer jacket. This metal layer is used to help block out electromagentic interference. You may recognize this concept from the metal mesh on the window of your microwave, which helps block out electromagentic radiation from escaping the microwave and damaging your body. In transmission systems, the high-voltage portion of the grid, the larger wires are generally air-insulated. This means that the bare conductor is able to cool off better (insulation for those thick and long conductors is also costly). Underground lines are always insulated as there can be a lot of moisture and other chemicals that could damage or corrode the conductor or conduct electricity in undesirable ways.