My lecture slides are posted at

http://www.physics.ohio-state.edu/~humanic/
Chapter 20

Electric Circuits
For a wide range of materials, the resistance $R$ of a piece of material of length $L$ and cross-sectional area $A$ is

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

Intuitively, this equation makes sense:

For larger $L$ --> $R$ increases

For larger $A$ --> $R$ decreases
## 20.3 Resistance and Resistivity

<table>
<thead>
<tr>
<th>Material</th>
<th>Resistivity $\rho$ (Ω · m)</th>
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<th>Resistivity $\rho$ (Ω · m)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conductors</strong></td>
<td></td>
<td><strong>Semiconductors</strong></td>
<td></td>
</tr>
<tr>
<td>Aluminum</td>
<td>$2.82 \times 10^{-8}$</td>
<td>Carbon</td>
<td>$3.5 \times 10^{-5}$</td>
</tr>
<tr>
<td>Copper</td>
<td>$1.72 \times 10^{-8}$</td>
<td>Germanium</td>
<td>$0.5^b$</td>
</tr>
<tr>
<td>Gold</td>
<td>$2.44 \times 10^{-8}$</td>
<td>Silicon</td>
<td>$20–2300^b$</td>
</tr>
<tr>
<td>Iron</td>
<td>$9.7 \times 10^{-8}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mercury</td>
<td>$95.8 \times 10^{-8}$</td>
<td>Mica</td>
<td>$10^{11}–10^{15}$</td>
</tr>
<tr>
<td>Nichrome (alloy)</td>
<td>$100 \times 10^{-8}$</td>
<td>Rubber (hard)</td>
<td>$10^{13}–10^{16}$</td>
</tr>
<tr>
<td>Silver</td>
<td>$1.59 \times 10^{-8}$</td>
<td>Teflon</td>
<td>$10^{16}$</td>
</tr>
<tr>
<td>Tungsten</td>
<td>$5.6 \times 10^{-8}$</td>
<td>Wood (maple)</td>
<td>$3 \times 10^{10}$</td>
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<td></td>
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</tbody>
</table>

$^a$ The values pertain to temperatures near 20 °C.

$^b$ Depending on purity.

\[ R = \rho \frac{L}{A} \]
20.3 Resistance and Resistivity

Example 3 Longer Extension Cords

The instructions for an electric lawn mower suggest that a 20-gauge extension cord can be used for distances up to 35 m, but a thicker 16-gauge cord should be used for longer distances. The cross sectional area of a 20-gauge wire is $5.2 \times 10^{-7} \text{ m}^2$, while that of a 16-gauge wire is $13 \times 10^{-7} \text{ m}^2$. Determine the resistance of (a) 35 m of 20-gauge copper wire and (b) 75 m of 16-gauge copper wire. The resistivity of Cu is $1.72 \times 10^{-8} \text{ Ωm}$.

(a) \[ R = \rho \frac{L}{A} = \frac{(1.72 \times 10^{-8} \text{ Ω} \cdot \text{m}) (35 \text{ m})}{5.2 \times 10^{-7} \text{ m}^2} = 1.2 \text{ Ω} \]

(b) \[ R = \rho \frac{L}{A} = \frac{(1.72 \times 10^{-8} \text{ Ω} \cdot \text{m}) (75 \text{ m})}{13 \times 10^{-7} \text{ m}^2} = 0.99 \text{ Ω} \]
20.3 Resistance and Resistivity

The resistivity of a material depends on its temperature as,

$$\rho = \rho_o [1 + \alpha (T - T_o)]$$

Resistivity at temperature $T_0$

temperature coefficient of resistivity

or, using

$$R = \rho \frac{L}{A} \quad \rightarrow \quad R = \rho_o \frac{L}{A} \left[1 + \alpha (T - T_o)\right]$$

As your book discusses, if the temperature of some materials is lowered below some critical temperature, $T_C$, they become **Superconductors** and $\rho = 0$, i.e. they have no resistance to current flow and so currents can persist in them indefinitely, e.g. for **lead**, $T_C = 7.20$ K
Example. The heating element of a kitchen stove has a resistivity of $6.8 \times 10^{-5} \, \Omega \cdot m$ at $T_0=320^\circ C$ and temperature coefficient of resistivity of $2.0 \times 10^{-3} \, (^\circ C)^{-1}$. Find the resistance of the heater wire at $420^\circ C$.

First find $\rho$ at $T = 420^\circ C$:

$$\rho = \rho_0 [1 + \alpha (T - T_0)]$$

$$= (6.8 \times 10^{-5}) [1 + (2.0 \times 10^{-3})(420 - 320)]$$

$$= 8.2 \times 10^{-5} \, \Omega \cdot m$$

Now find $R$ at $420^\circ C$ using this and the dimensions of the heater wire shown:

$$R = \frac{\rho L}{A} = \frac{(8.2 \times 10^{-5})(1.1)}{(3.1 \times 10^{-6})}$$

$$= 29 \, \Omega$$
20.4 Electric Power

Suppose some charge $\Delta q$ emerges from a battery in time $\Delta t$ and the potential difference between the battery terminals is $V$. The battery is putting out power to the circuit since it is outputting energy per time, 

$$P = \frac{(\Delta q)V}{\Delta t} = \frac{\Delta q}{\Delta t} V = IV$$
20.4 Electric Power

ELECTRIC POWER

When there is current in a circuit as a result of a voltage, the electric power delivered to the circuit is:

\[ P = IV \]

SI Unit of Power: watt (W)

Many electrical devices are essentially resistors, so the power dissipated by them can be calculated using their resistance, \( R \)

\[ P = I(IV) = I^2R \]

\[ P = \left( \frac{V}{R} \right) V = \frac{V^2}{R} \]
**Example 5 The Power and Energy Used in a Flashlight**

In the flashlight, the current is 0.40A and the voltage is 3.0 V. Find (a) the power delivered to the bulb and (b) the energy dissipated in the bulb in 5.5 minutes of operation.
20.4 Electric Power

(a) \[ P = IV = (0.40 \text{ A})(3.0 \text{ V}) = 1.2 \text{ W} \]

(b) \[ E = Pt = (1.2 \text{ W})(330 \text{ s}) = 4.0 \times 10^2 \text{ J} \]
There are many circuits in which more than one device is connected to a voltage source.

**Series wiring means that the devices are connected in such a way that there is the same electric current through each device.**
20.6 Series Wiring

\[ V = V_1 + V_2 = IR_1 + IR_2 = I(R_1 + R_2) = IR_S \]

Equivalent series resistance

Series resistors \[ R_S = R_1 + R_2 + R_3 + \cdots \]
20.6 Series Wiring

Example 8 Resistors in a Series Circuit

A 6.00 Ω resistor and a 3.00 Ω resistor are connected in series with a 12.0 V battery. Assuming the battery contributes no resistance to the circuit, find (a) the current, (b) the power dissipated in each resistor, and (c) the total power delivered to the resistors by the battery.
20.6 Series Wiring

(a) \( R_s = 6.00 \, \Omega + 3.00 \, \Omega = 9.00 \, \Omega \)
\[ I = \frac{V}{R_s} = \frac{12.0 \, \text{V}}{9.00 \, \Omega} = 1.33 \, \text{A} \]

(b) For \( R = 6.00 \, \Omega \): \[ P = I^2 R = (1.33 \, \text{A})^2 (6.00 \, \Omega) = 10.6 \, \text{W} \]
For \( R = 3.00 \, \Omega \): \[ P = I^2 R = (1.33 \, \text{A})^2 (3.00 \, \Omega) = 5.31 \, \text{W} \]

(c) Total power dissipated: \[ P = 10.6 \, \text{W} + 5.31 \, \text{W} = 15.9 \, \text{W} \]