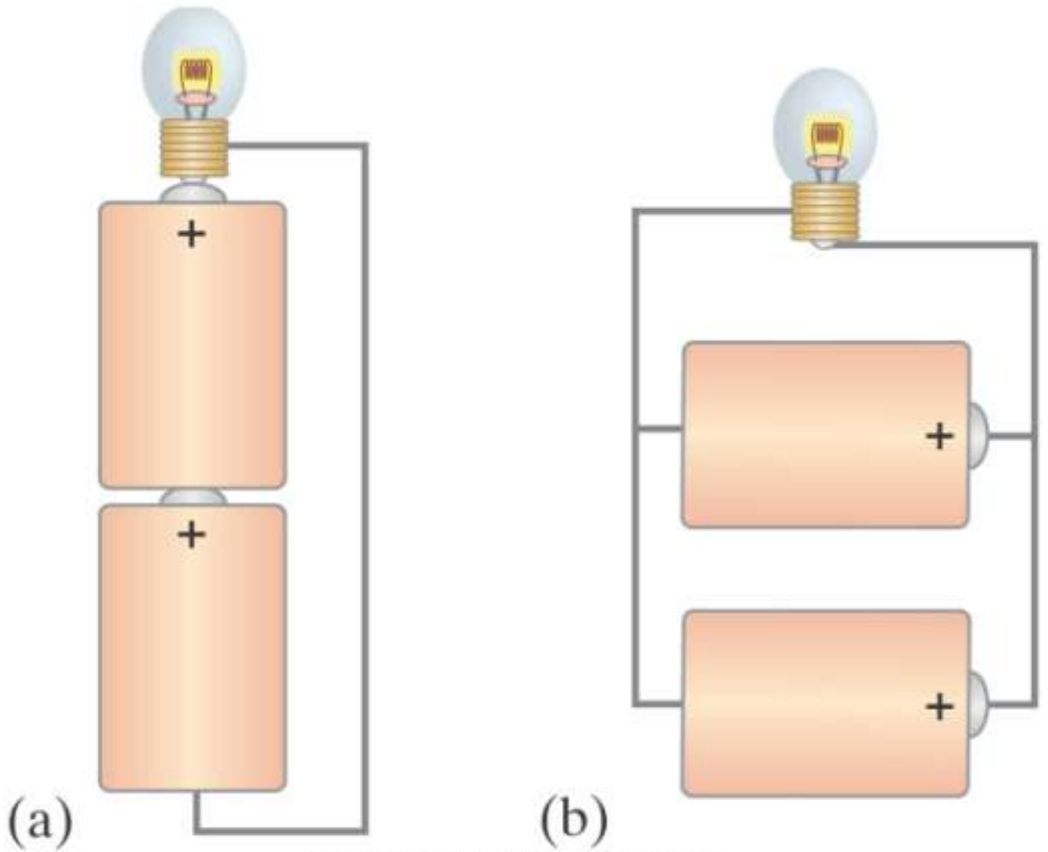
Chapter 18

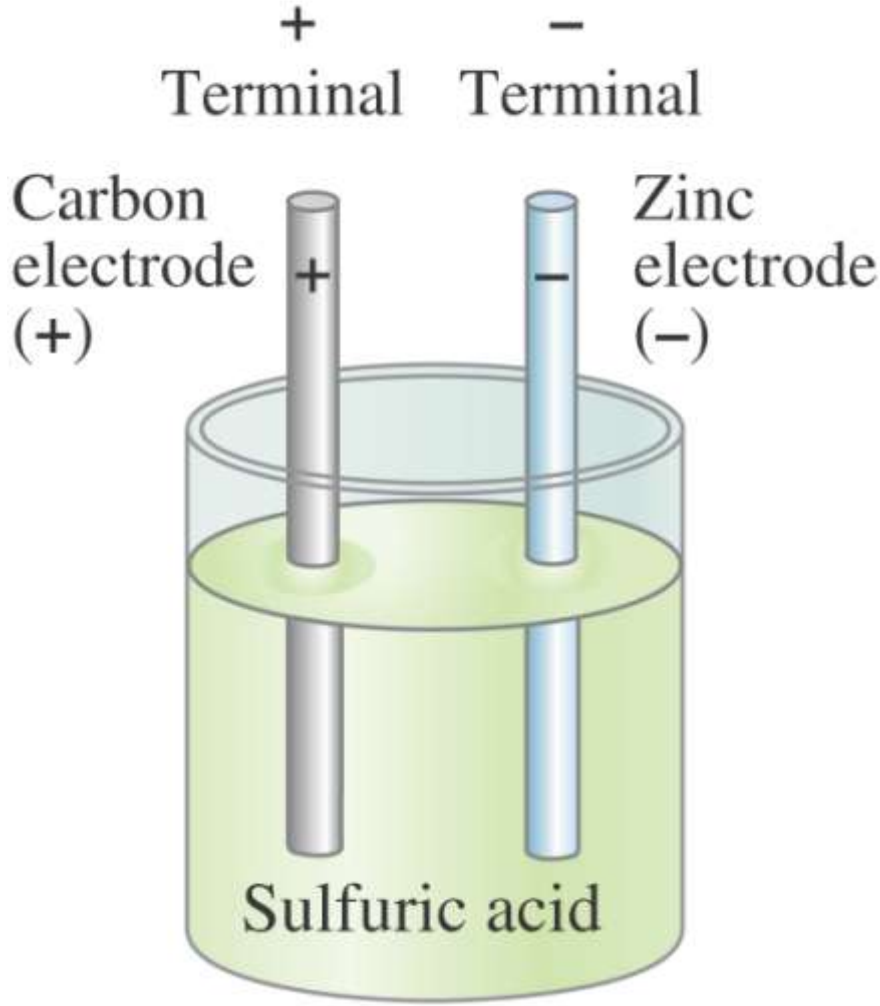
Electric Currents



18.1 The Electric Battery

Volta discovered that electricity could be created if dissimilar metals were connected by a conductive solution called an electrolyte.

This is a simple electric cell.



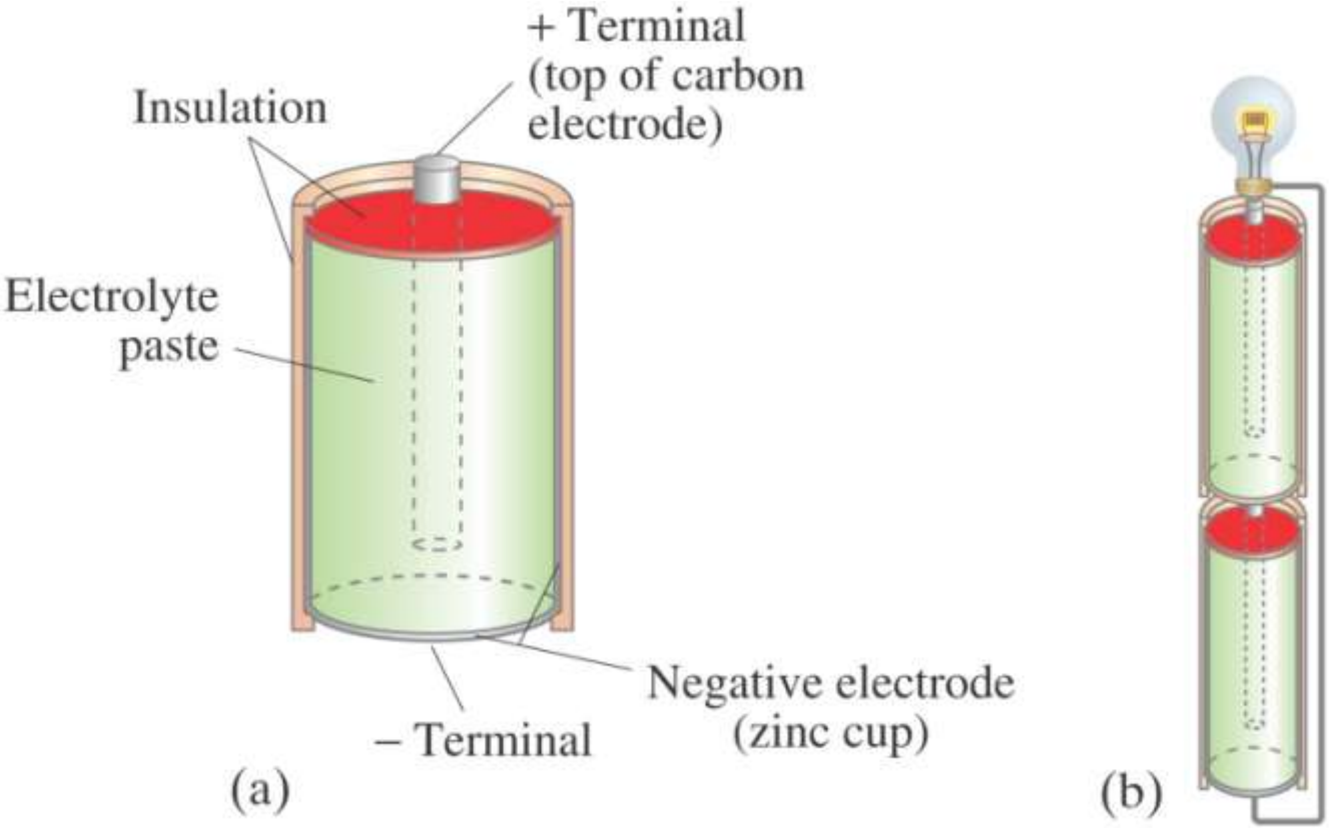
18.1 The Electric Battery

A battery transforms chemical energy into electrical energy.

Chemical reactions within the cell create a potential difference between the terminals by slowly dissolving them. This potential difference can be maintained even if a current is kept flowing, until one or the other terminal is completely dissolved.

18.1 The Electric Battery

Several cells connected together make a battery, although now we refer to a single cell as a battery as well.



18.2 Electric Current

Electric current is the rate of flow of charge through a conductor:

$$I = \frac{\Delta Q}{\Delta t} \qquad \textbf{(18-1)}$$

Unit of electric current: the ampere, A.

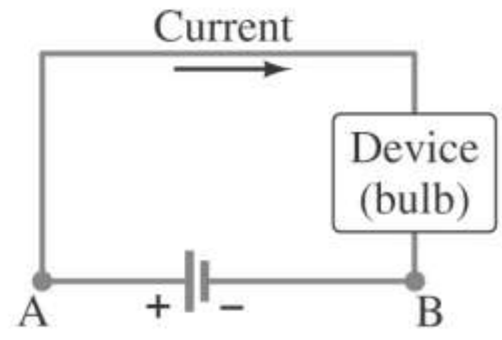
1 A = 1 C/s.

18.2 Electric Current

A complete circuit is one where current can flow all the way around. Note that the schematic drawing doesn't look much like the physical circuit!

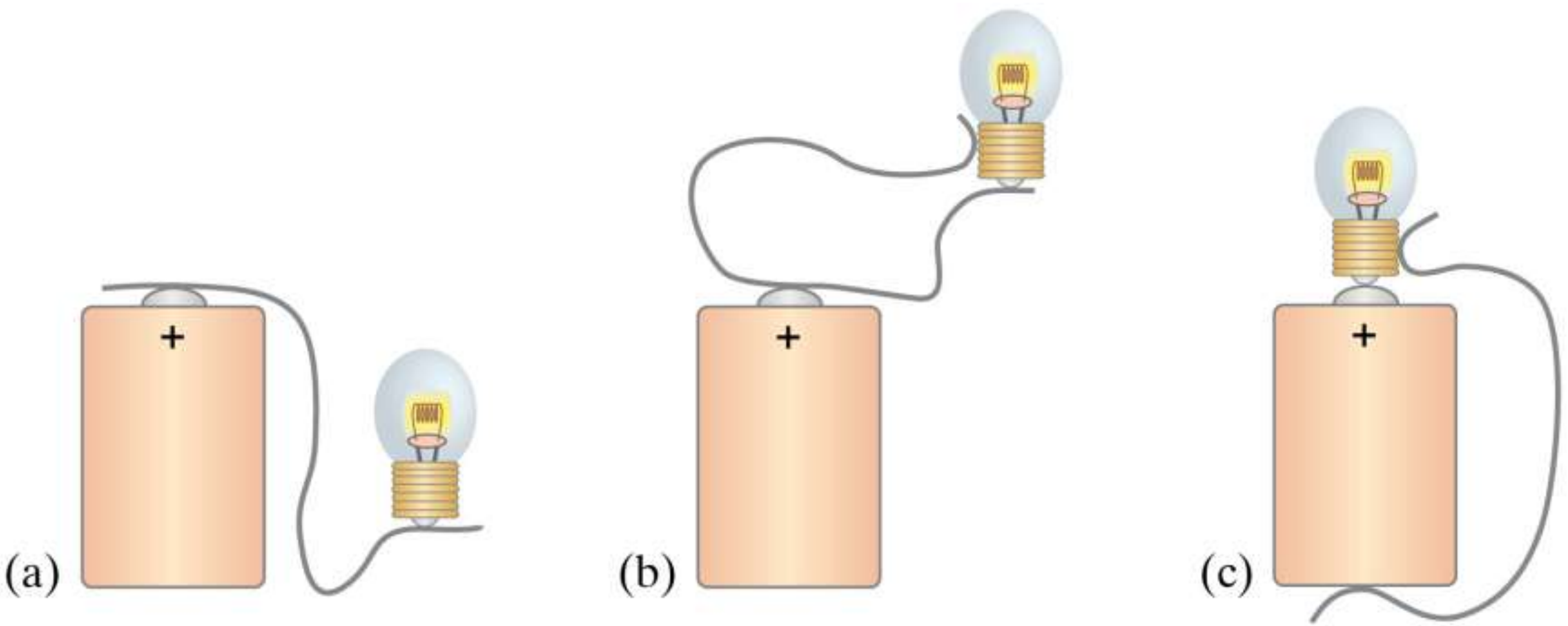
(a)

(b)



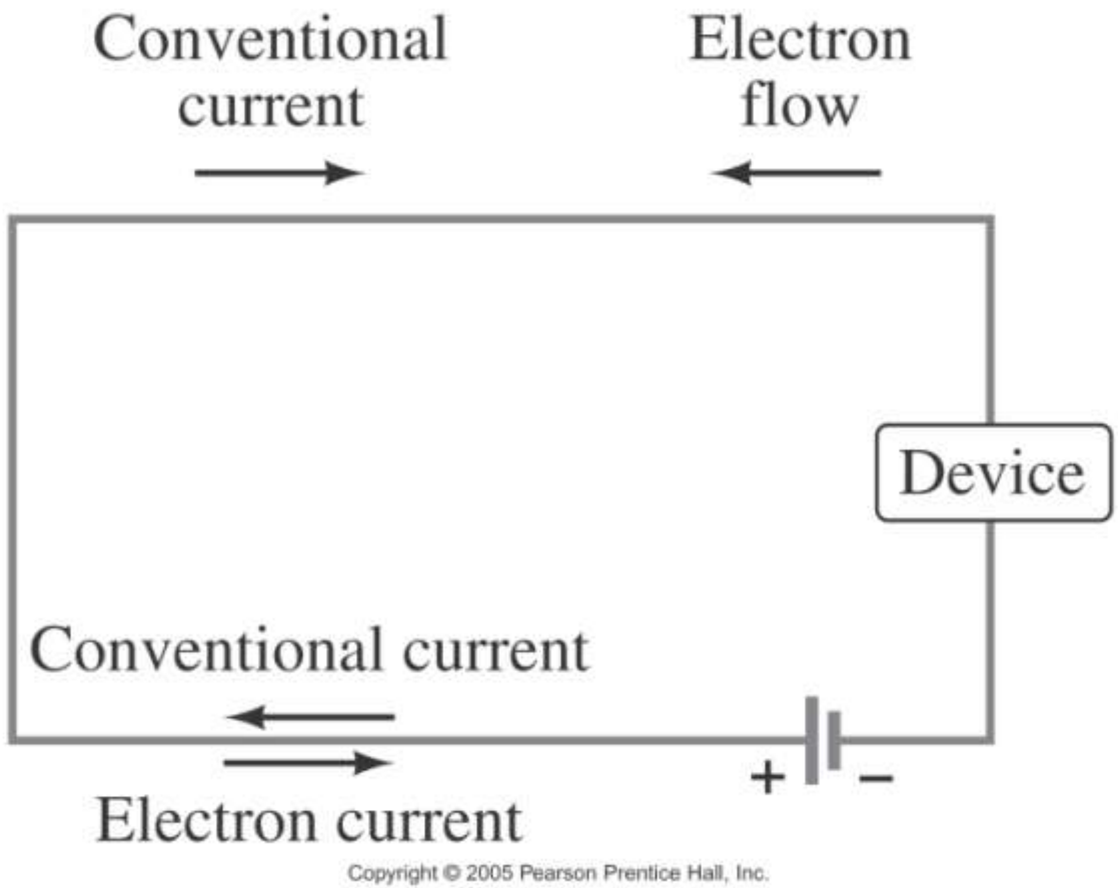
18.2 Electric Current

In order for current to flow, there must be a path from one battery terminal, through the circuit, and back to the other battery terminal. Only one of these circuits will work:



18.2 Electric Current

By convention, current is defined as flowing from + to -. Electrons actually flow in the opposite direction, but not all currents consist of electrons.



18.3 Ohm's Law: Resistance and Resistors

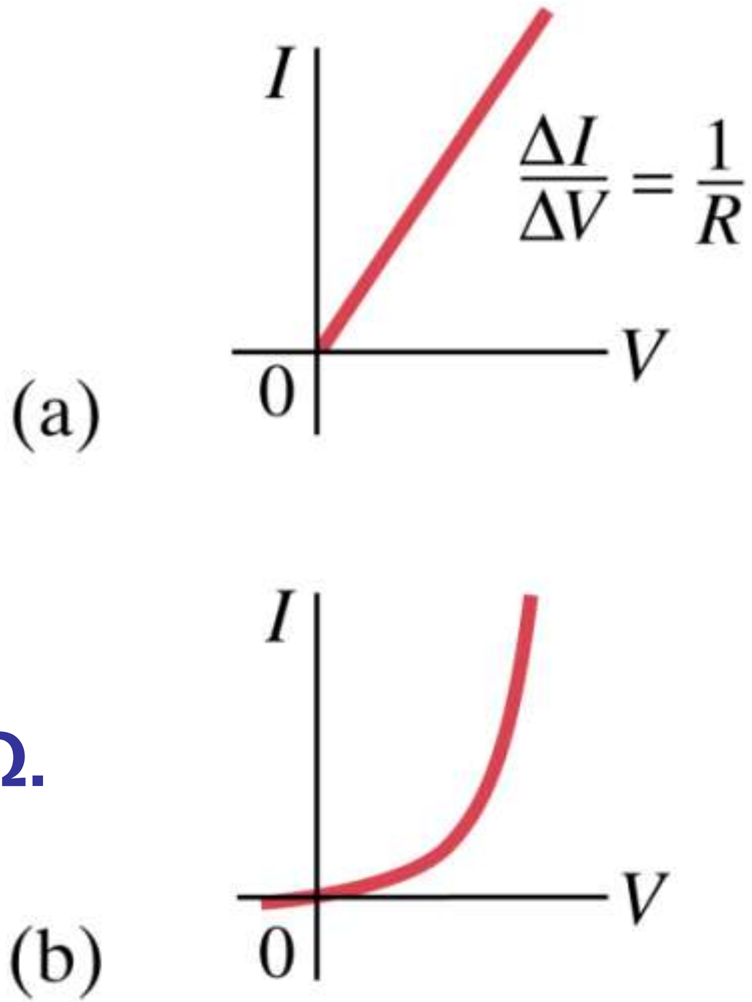
The ratio of voltage to current is called the resistance:

$$R = \frac{V}{I} \qquad \textbf{(18-2a)}$$

$$\boxed{V = IR} \qquad \textbf{(18-2b)}$$

18.3 Ohm's Law: Resistance and Resistors

In many conductors, the resistance is independent of the voltage; this relationship is called Ohm's law. Materials that do not follow Ohm's law are called nonohmic.



Unit of resistance: the ohm, Ω.

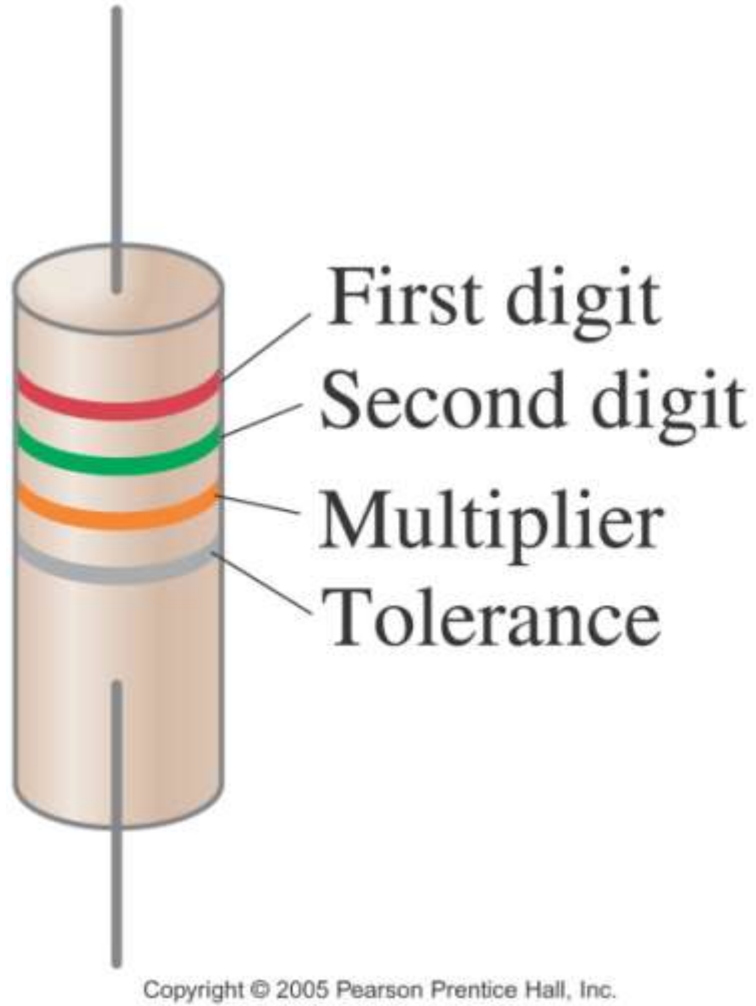
1 Ω = 1 V/A.

18.3 Ohm's Law: Resistance and Resistors

[Time for a Gizmo!]

18.3 Ohm's Law: Resistance and Resistors

Standard resistors are manufactured for use in electric circuits; they are color-coded to indicate their value and precision.



Mnemonic Devices

My Very Energetic Mother Just Served us Noodles

The names of the planets in the solar system, in order from the Sun out: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune- Poor Pluto!

Mnemonic Devices

ROY G BIV

The colors of the rainbow in the order of their appearance: red, orange, yellow, green, blue, indigo, and violet

Mnemonic Devices

Divorced, beheaded, died.
Divorced, beheaded, survived

For remembering the fates of King Henry VIII’s six wives.

Mnemonic Devices

Every Good Boy Deserves Fudge and FACE

In music theory, these represent the notes of the treble (G) clef: the lines (EGBDF) and the spaces (FACE).

Mnemonic Devices

HOMES

The names of the Great Lakes:
Huron, Ontario, Michigan, Erie, Superior

Mnemonic Devices

ABC

CPR Procedure: Airway, Breathing, Circulation

Mnemonic Devices

Kings Play Chess On Funny Green Squares

The Linnean classification system: Kingdom, Phylum, Class, Order, Genus, Species

18.3 Ohm's Law: Resistance and Resistors

Resistor Color Code

Color	Number	Multiplier	Tolerance
Black	0	1	
Brown	1	10^1	
Red	2	10^2	
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Gray	8	10^8	
White	9	10^9	
Gold		10^{-1}	5%
Silver		10^{-2}	10%
No color			20%

18.3 Resistor Code Mnemonic

B
B
R
O
Y
G
B
V
G
W
G
S
N

18.3 Ohm's Law: Resistance and Resistors

Some clarifications:

- **Batteries maintain a (nearly) constant potential difference; the current varies.**

- **Resistance is a property of a material or device.**

- **Current is not a vector but it does have a direction.**

- **Current and charge do not get used up. Whatever charge goes in one end of a circuit comes out the other end.**

18.4 Resistivity

The resistance of a wire is directly proportional to its length and inversely proportional to its cross-sectional area:

$$R = \rho \frac{L}{A} \qquad \textbf{(18-3)}$$

The constant ρ, the resistivity, is characteristic of the material.

18.4 Resistivity

[Time for a Gizmo!]

18.4 Resistivity

TABLE 18–1 Resistivity and Temperature Coefficients (at 20°C)

Material	Resistivity, ρ ($\Omega \cdot$ m)	Temperature Coefficient, α $(\mathrm{C}^\circ)^{-1}$
Conductors		
Silver	1.59×10^{-8}	0.0061
Copper	1.68×10^{-8}	0.0068
Gold	2.44×10^{-8}	0.0034
Aluminum	2.65×10^{-8}	0.00429
Tungsten	5.6×10^{-8}	0.0045
Iron	9.71×10^{-8}	0.00651
Platinum	10.6×10^{-8}	0.003927
Mercury	98×10^{-8}	0.0009
Nichrome (Ni, Fe, Cr alloy)	100×10^{-8}	0.0004
Semiconductors†		
Carbon (graphite)	$(3–60) \times 10^{-5}$	−0.0005
Germanium	$(1–500) \times 10^{-3}$	−0.05
Silicon	0 .1–60	−0.07
Insulators		
Glass	$10^{9} – 10^{12}$	
Hard rubber	$10^{13} – 10^{15}$	

† Values depend strongly on the presence of even slight amounts of impurities.

18.4 Resistivity

For any given material, the resistivity increases with temperature:

$$\rho_T = \rho_0\left[1 + \alpha\left(T - T_0\right)\right] \qquad (18\text{-}4)$$

Semiconductors are complex materials, and may have resistivities that decrease with temperature.

18.5 Electric Power

Power, as in kinematics, is the energy transformed by a device per unit time:

$$P = \frac{\text{energy transformed}}{\text{time}} = \frac{QV}{t}$$

$$\boxed{P = IV} \qquad \textbf{(18-5)}$$

18.5 Electric Power

The unit of power is the watt, W.

For ohmic devices, we can make the substitutions:

$$P = IV = I(IR) = I^2R \qquad \textbf{(18-6a)}$$

$$P = IV = \left(\frac{V}{R}\right)V = \frac{V^2}{R} \qquad \textbf{(18-6b)}$$

18.5 Electric Power

What you pay for on your electric bill is not power, but energy – the power consumption multiplied by the time.

We have been measuring energy in joules, but the electric company measures it in kilowatt-hours, kWh.

$$\text{One kWh} = (1000\text{ W})(3600\text{ s}) = 3.60 \times 10^6\text{ J}$$

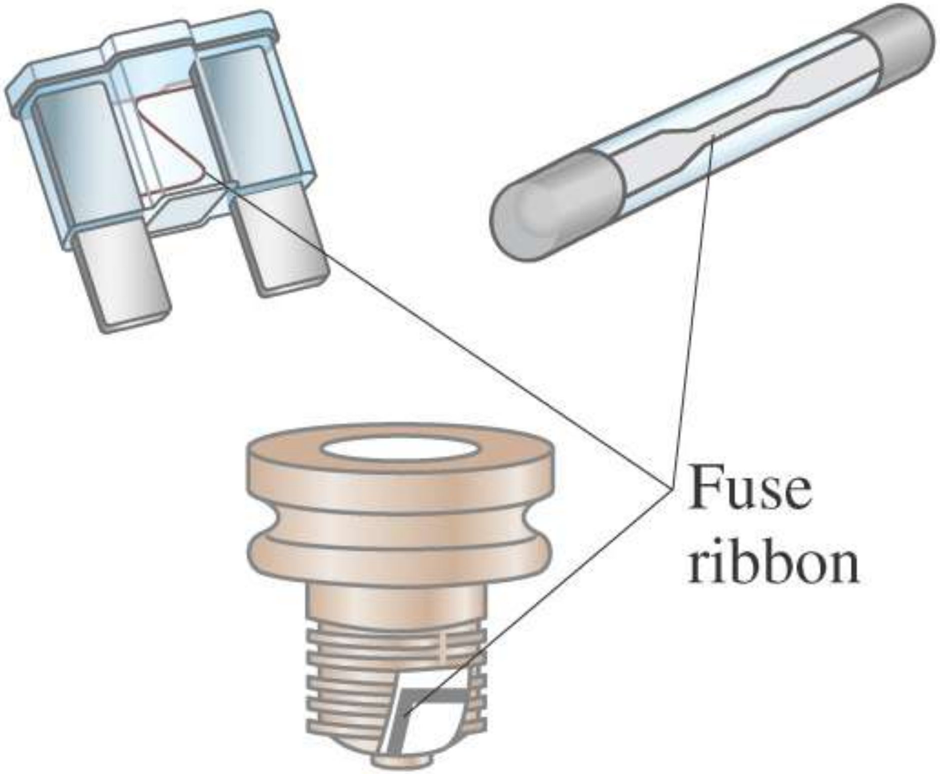
18.6 Power in Household Circuits

The wires used in homes to carry electricity have very low resistance. However, if the current is high enough, the power will increase and the wires can become hot enough to start a fire.

To avoid this, we use fuses or circuit breakers, which disconnect when the current goes above a predetermined value.

18.6 Power in Household Circuits

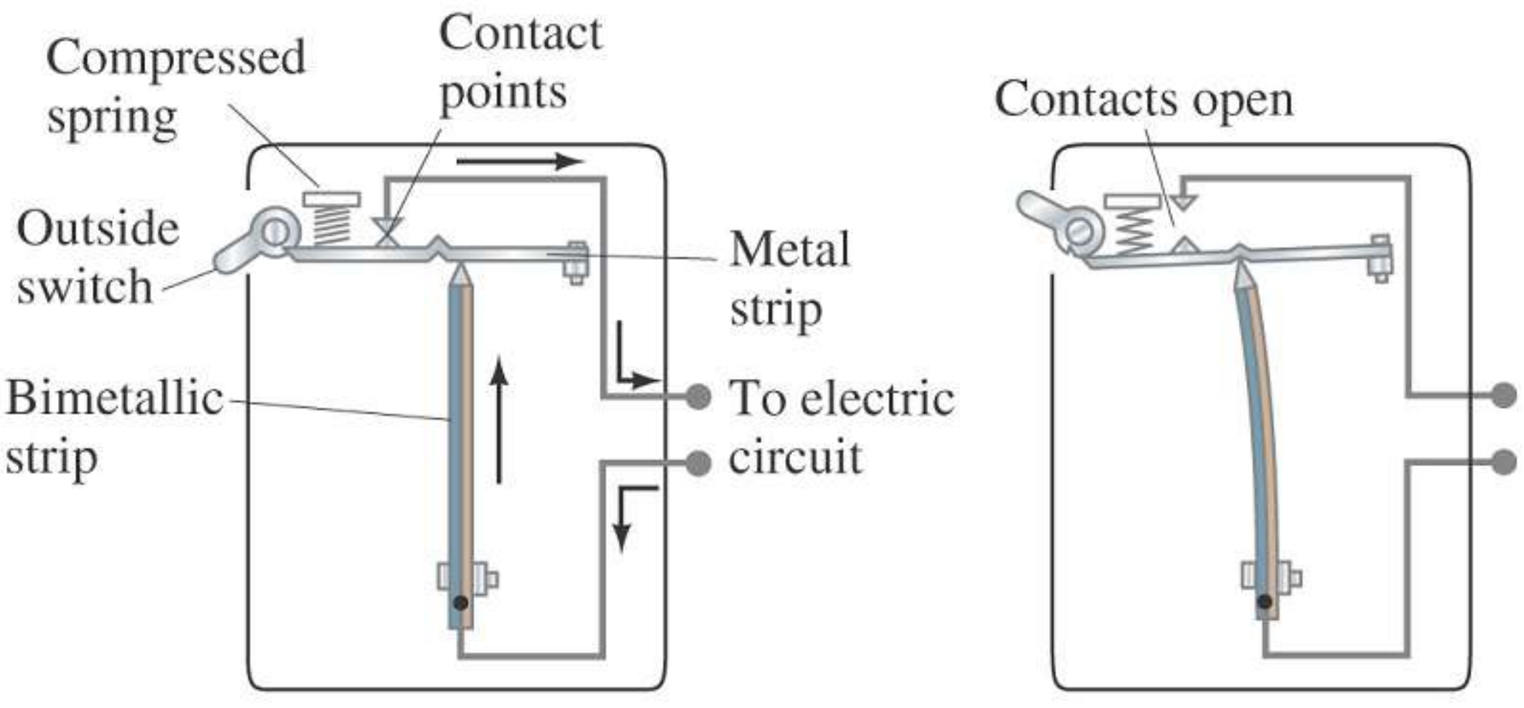
Fuses are one-use items – if they blow, the fuse is destroyed and must be replaced.



(a) Types of fuses

18.6 Power in Household Circuits

Circuit breakers, which are now much more common in homes than they once were, are switches that will open if the current is too high; they can then be reset.

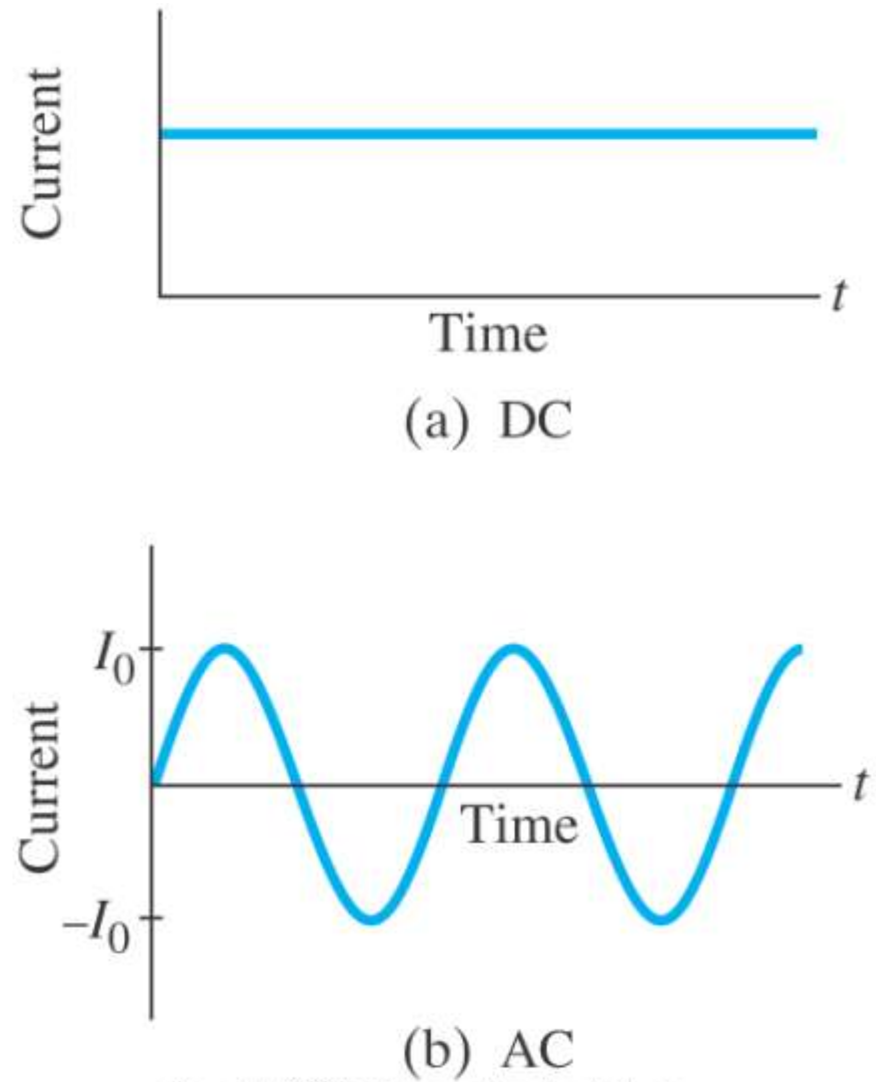


(b) Circuit breaker (closed)

(c) Circuit breaker (open)

18.7 Alternating Current

Current from a battery flows steadily in one direction (direct current, DC). Current from a power plant varies sinusoidally (alternating current, AC).



18.7 Alternating Current

Time for a Gizmo!

18.7 Alternating Current

The voltage varies sinusoidally with time:

$$V = V_0 \sin 2\pi f t = V_0 \sin \omega t$$

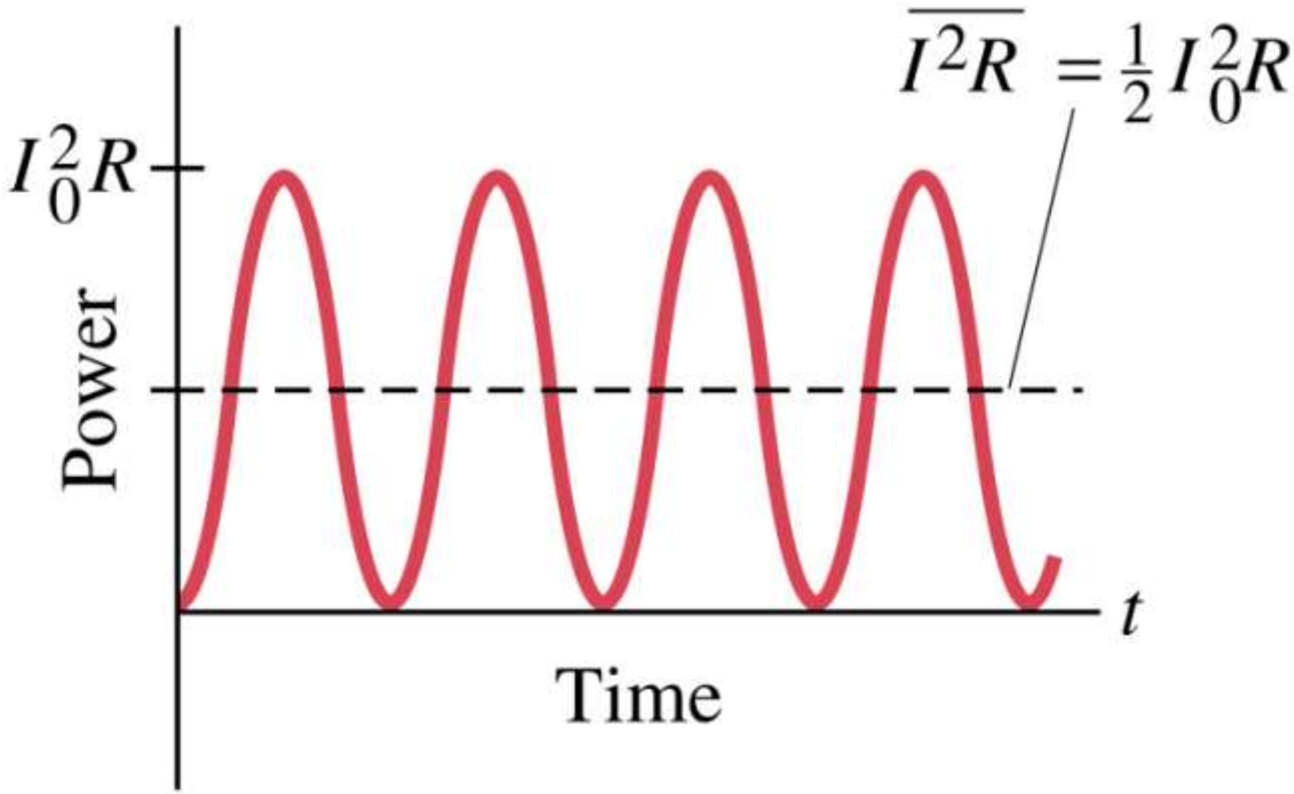
as does the current:

$$I = \frac{V}{R} = \frac{V_0}{R} \sin \omega t = I_0 \sin \omega t \qquad \textbf{(18-7)}$$

18.7 Alternating Current

Multiplying the current and the voltage gives the power:

$$P = I^2R = I_0^2 R \sin^2 \omega t$$



18.7 Alternating Current

Usually we are interested in the average power:

$$\overline{P} = \tfrac{1}{2} I_0^2 R$$

$$\overline{P} = \frac{1}{2} \frac{V_0^2}{R}$$

18.7 Alternating Current

The current and voltage both have average values of zero, so we square them, take the average, then take the square root, yielding the root mean square (rms) value.

$$I_{\text{rms}} = \sqrt{\overline{I^2}} = \frac{I_0}{\sqrt{2}} = 0.707 I_0 \qquad \textbf{(18-8a)}$$

$$V_{\text{rms}} = \sqrt{\overline{V^2}} = \frac{V_0}{\sqrt{2}} = 0.707 V_0 \qquad \textbf{(18-8b)}$$

[Conductivity Movie]