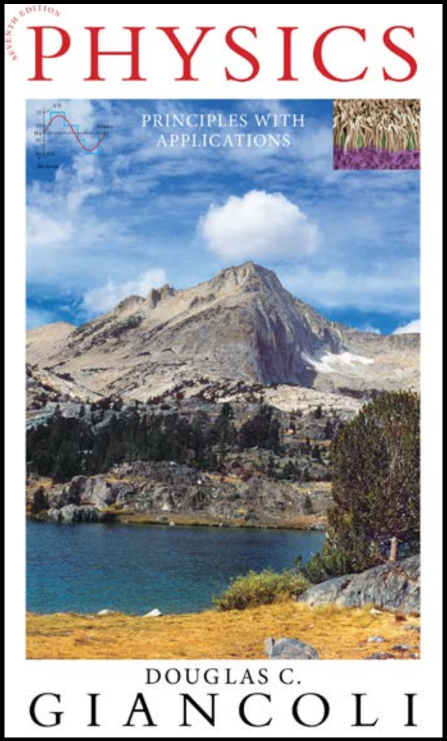

Lecture PowerPoints

Chapter 18
Physics: Principles with Applications, 7th edition
Giancoli

Chapter 18
Electric Currents

Contents of Chapter 18

- The Electric Battery
- Electric Current
- Ohm’s Law: Resistance and Resistors
- Resistivity
- Electric Power

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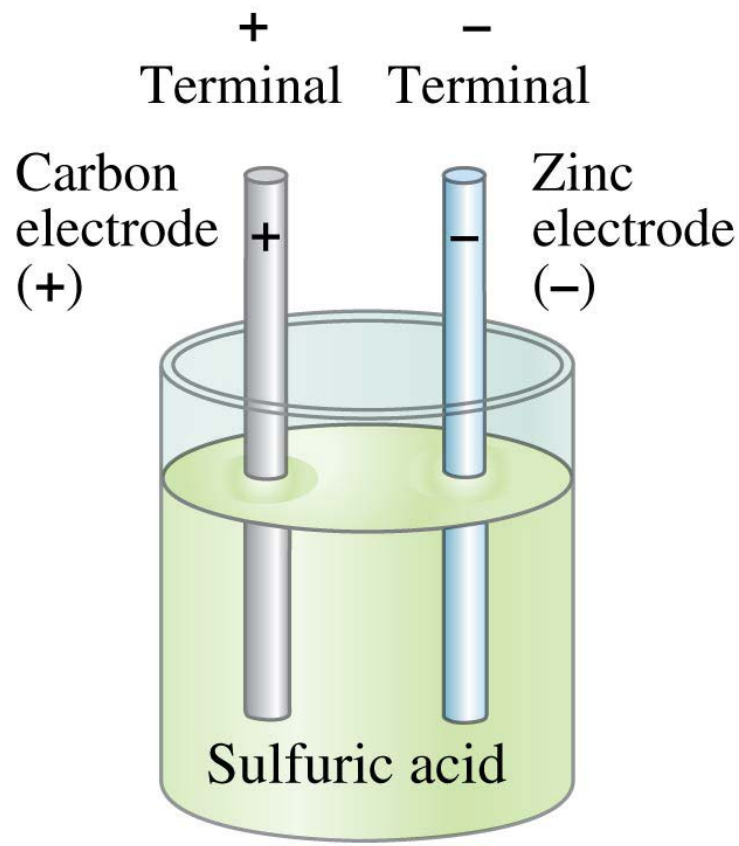
- Power in Household Circuits
- Alternating Current
- Microscopic View of Electric Current
- Superconductivity
- Electrical Conduction in the Human Nervous System

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.



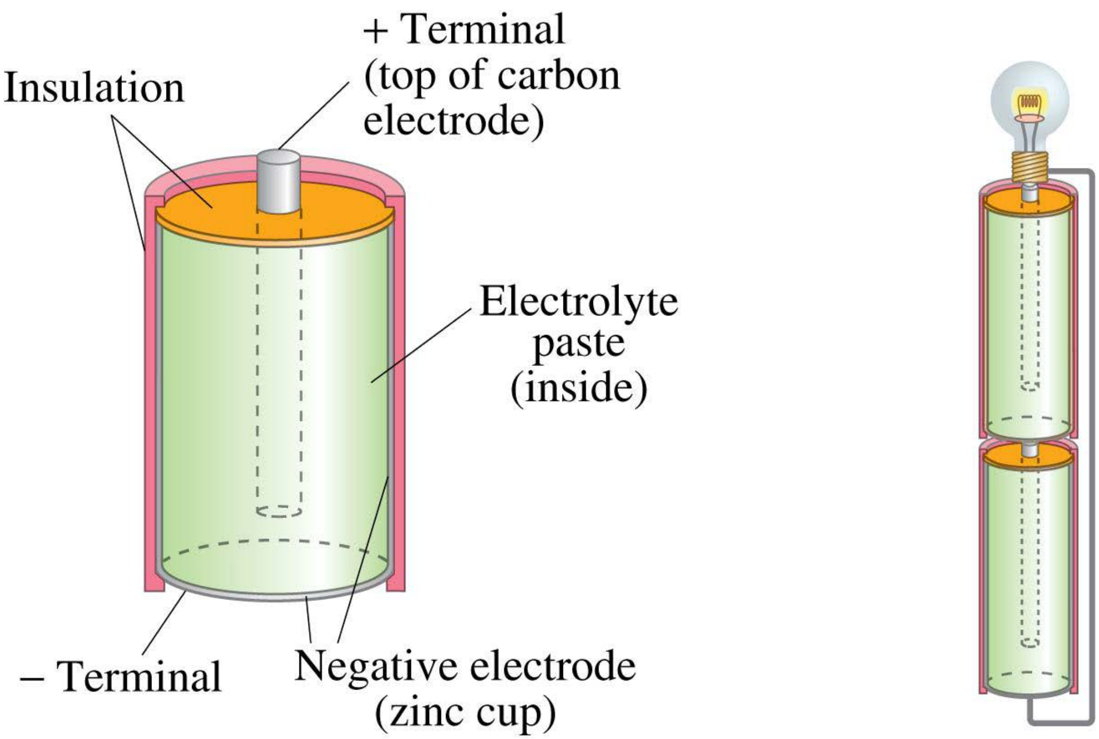
18-1 The Electric Battery

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.



(a) One D-cell (b) Two AA batteries

18-2 Electric Current

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

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

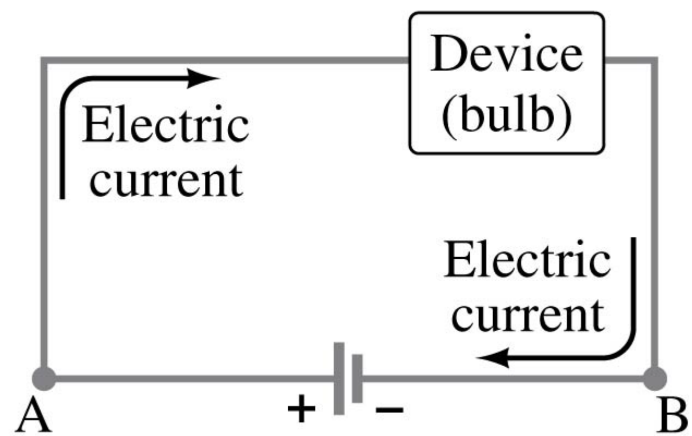
Unit of electric current: the ampere, A.

$$1\ \text{A} = 1\ \text{C/s}$$

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!

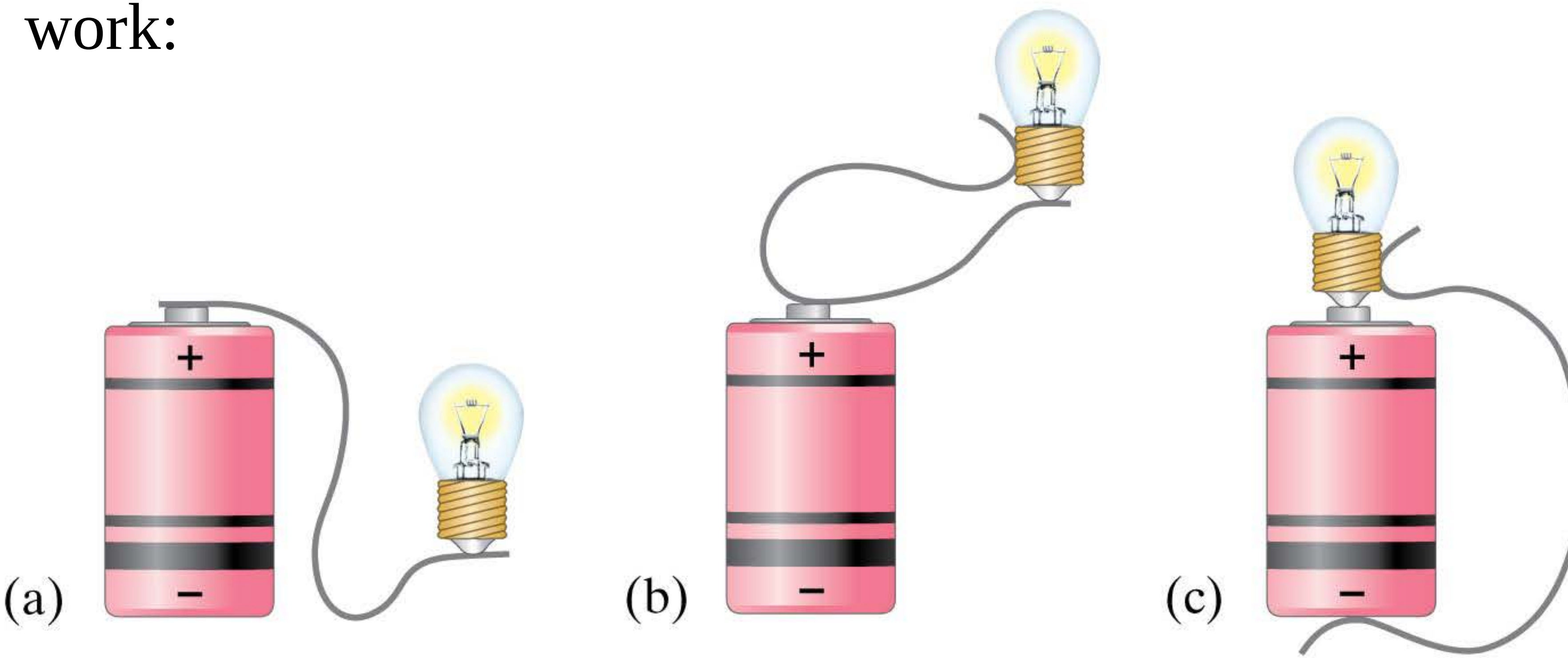
(a)



(b)

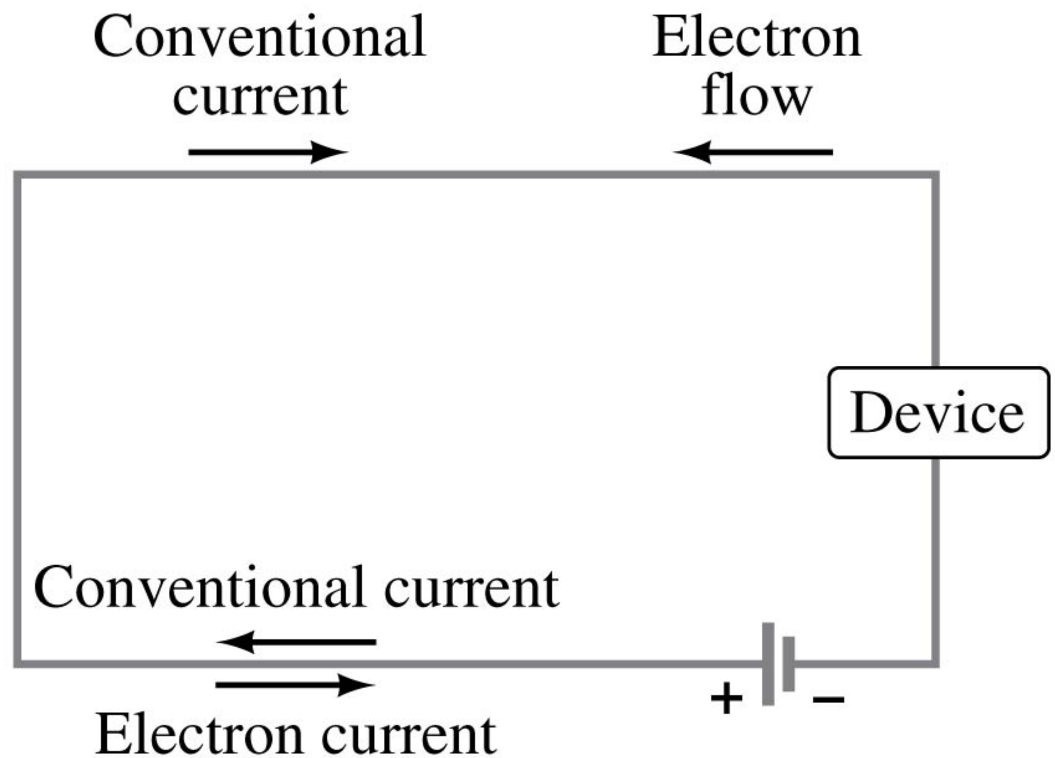
18-2 Electric Current

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

Experimentally, it is found that the current in a wire is proportional to the potential difference between its ends:

$$I \propto V$$

18-3 Ohm's Law: Resistance and Resistors

The ratio of voltage to current is called the resistance:

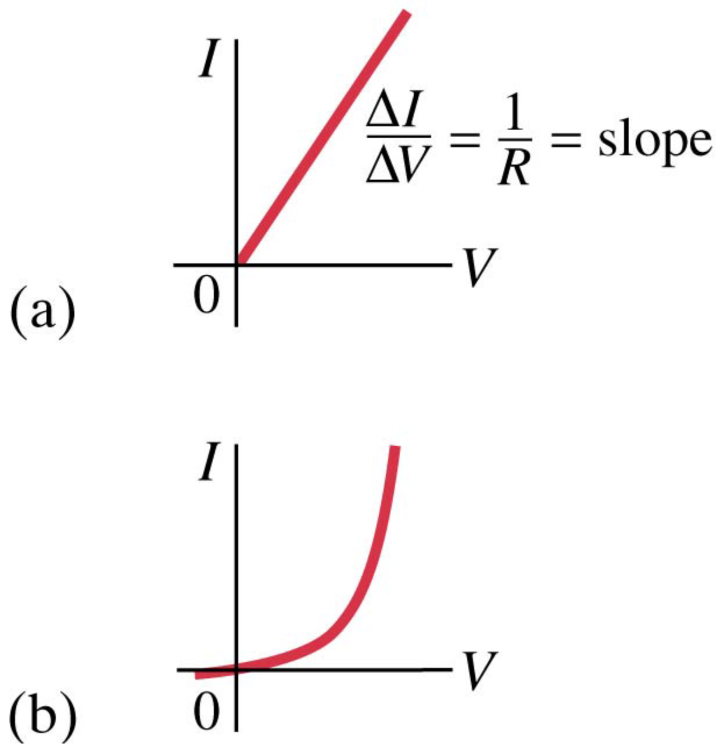
$$\boxed{V = IR.} \qquad (18\text{-}2)$$

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.

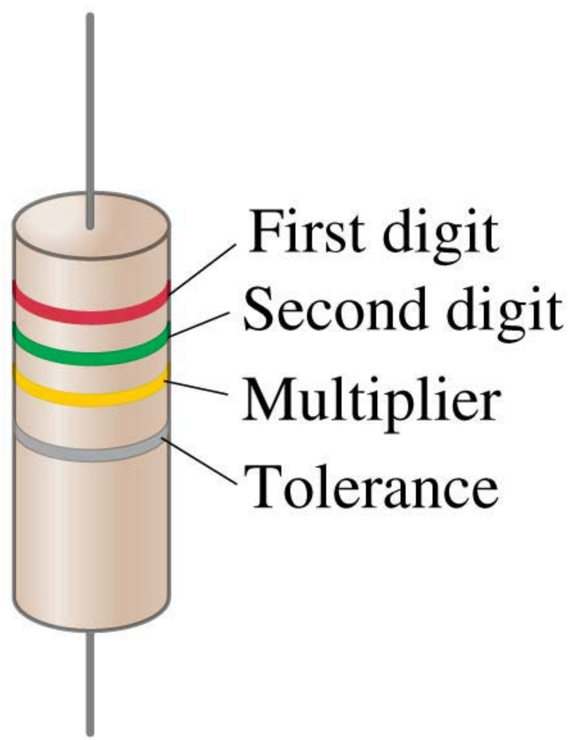
Unit of resistance:
the ohm, Ω.

$$1\ \Omega = 1\ \text{V/A}$$



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.



18-3 Ohm's Law: Resistance and Resistors

Resistor Color Code

Color	Number	Multiplier	Tolerance
Black	0	1	
Brown	1	10^1	1%
Red	2	10^2	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 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:

$$R = \rho \frac{\ell}{A} \qquad (18\text{-}3)$$

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

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)	$(3\text{–}60) \times 10^{-5}$	−0.0005
Germanium	$(1\text{–}500) \times 10^{-3}$	−0.05
Silicon	0.1–60	−0.07
Insulators		
Glass	$10^{9}\text{–}10^{12}$	
Hard rubber	$10^{13}\text{–}10^{15}$	

‡ 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:

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

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

18-5 Electric Power

The unit of power is the watt, W.

For ohmic devices, we can make the substitutions:

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

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

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.

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

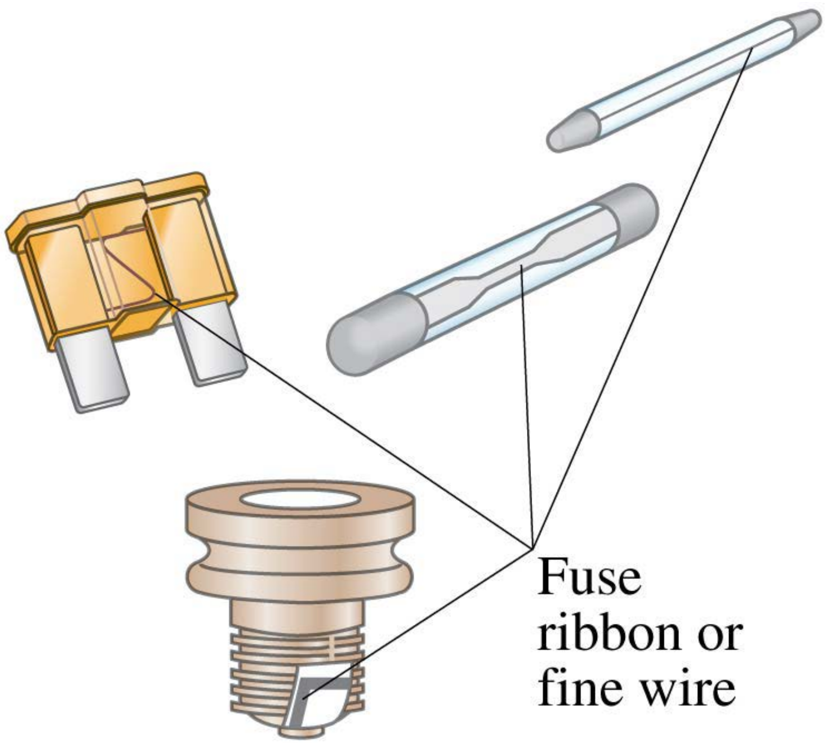
18-6 Power in Household Circuits

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

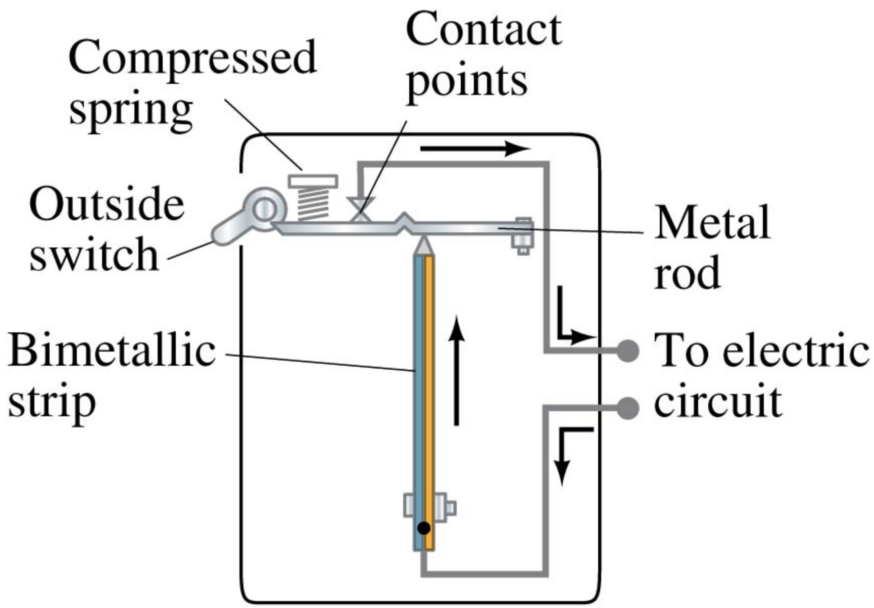
Fuses are one-use items—if they blow, the fuse is destroyed and must be replaced.



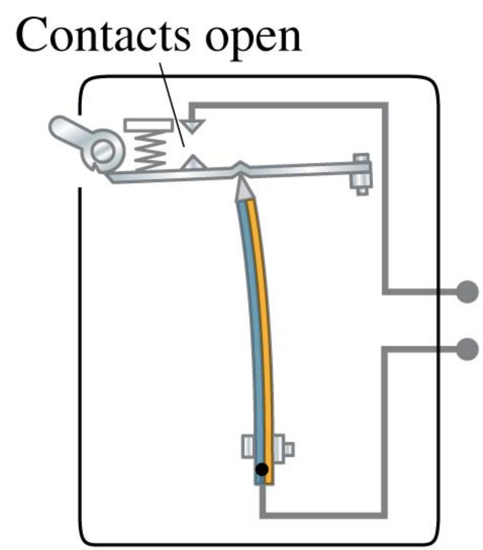
(a) Types of fuses

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.



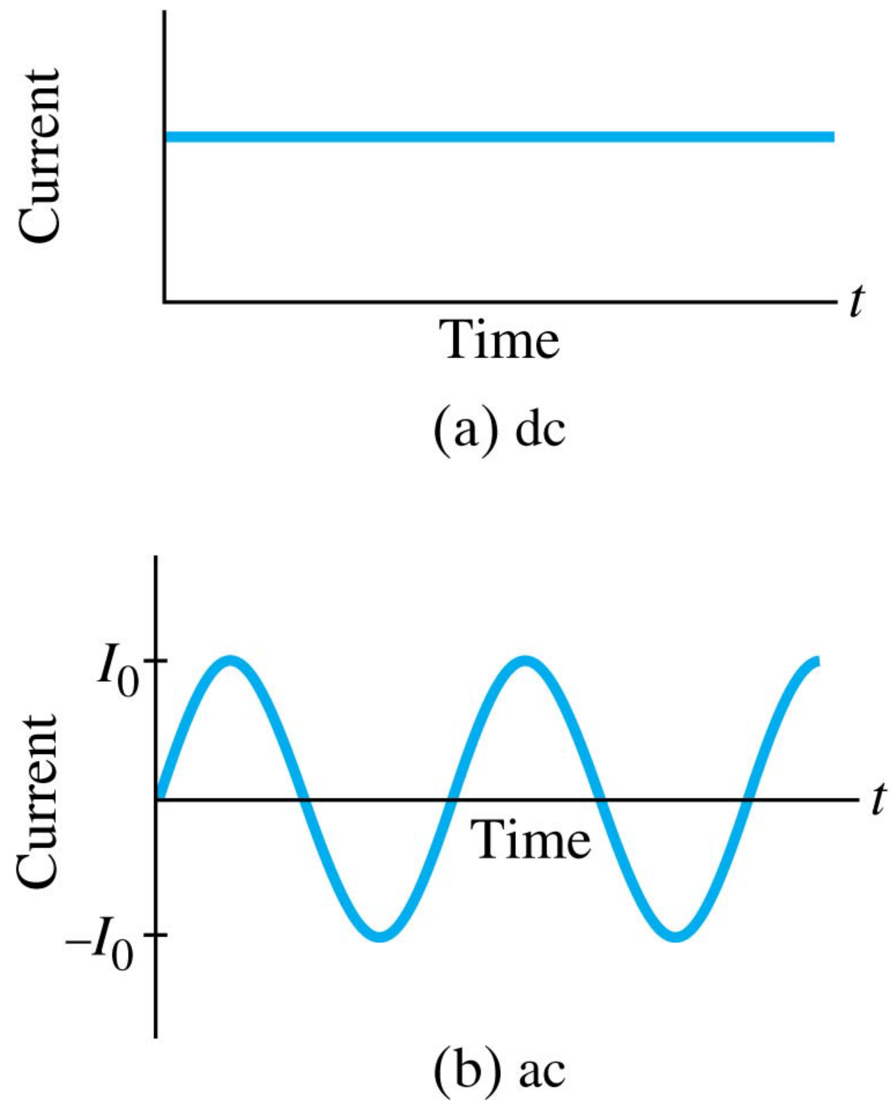
(b) Circuit breaker (closed)



(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

The voltage varies sinusoidally with time:

$$V = V_0 \sin 2\pi f t = V_0 \sin \omega t \qquad (18\text{-}7a)$$

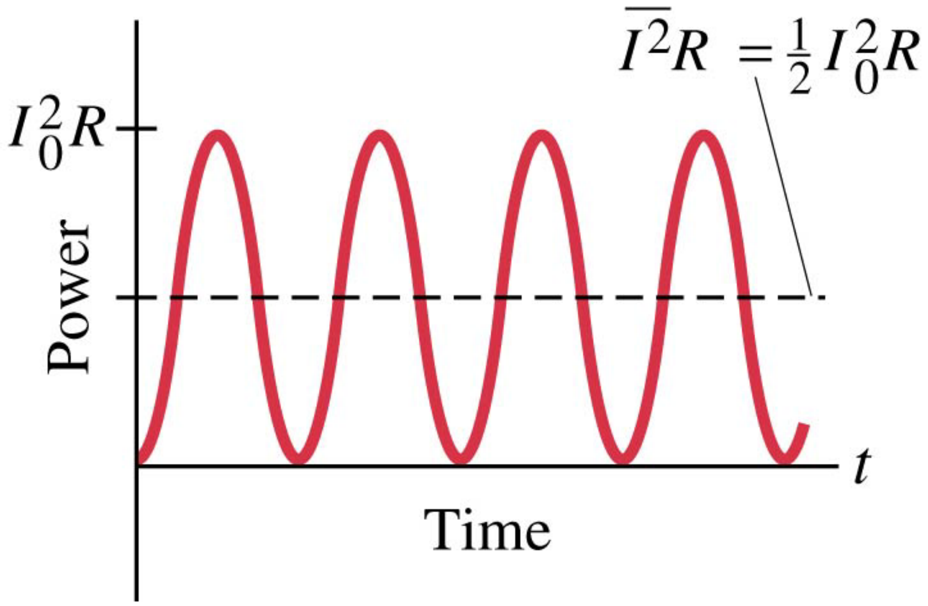
as does the current:

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

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:

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

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

18-7 Alternating Current

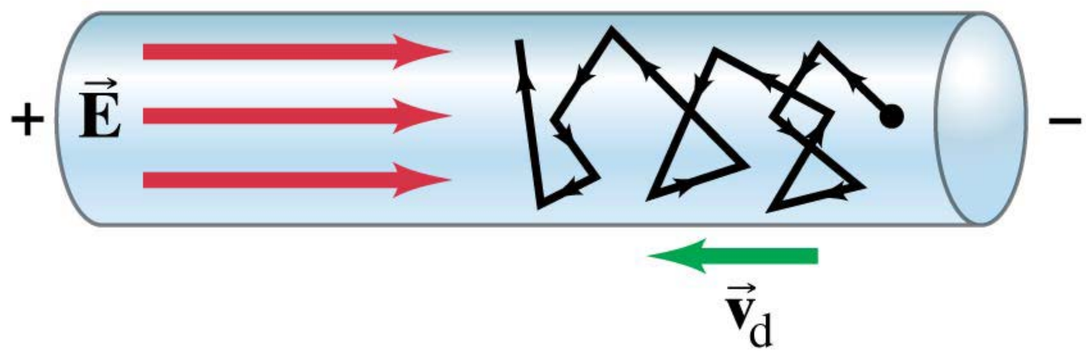
The current and voltage both have average values of zero, so we square them, take the average, then take the square root, yielding the root mean square (rms) value.

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

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

18-8 Microscopic View of Electric Current

Electrons in a conductor have large, random speeds just due to their temperature. When a potential difference is applied, the electrons also acquire an average drift velocity, which is generally considerably smaller than the thermal velocity.



18-8 Microscopic View of Electric Current

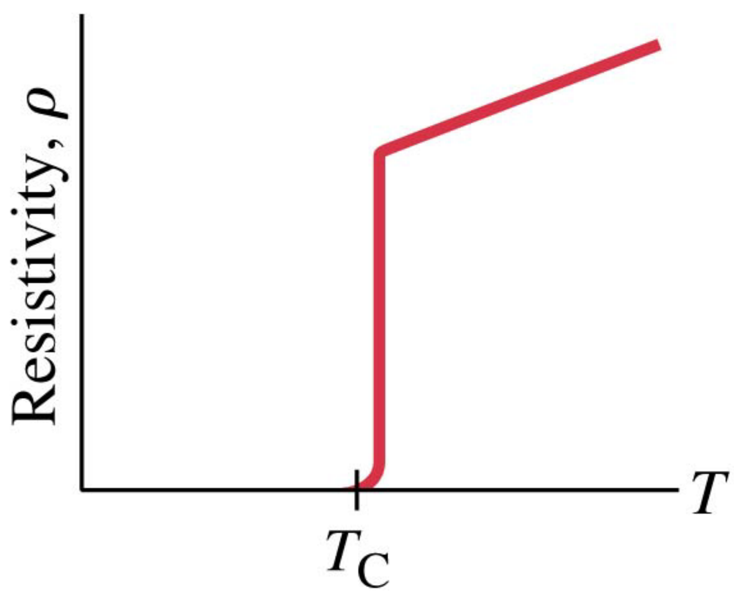
This drift speed is related to the current in the wire, and also to the number of electrons per unit volume.

$$\begin{aligned}\Delta Q &= (\text{number of charges, } N) \times (\text{charge per particle}) \\ &= (nV)(e) = \big(nAv_{\mathrm{d}}\,\Delta t\big)(e).\end{aligned}$$

$$I = \frac{\Delta Q}{\Delta t} = neAv_{\mathrm{d}} \qquad (18\text{-}10)$$

18-9 Superconductivity

In general, resistivity decreases as temperature decreases. Some materials, however, have resistivity that falls abruptly to zero at a very low temperature, called the critical temperature, T_C.



18-9 Superconductivity

Experiments have shown that currents, once started, can flow through these materials for years without decreasing even without a potential difference.

Critical temperatures are low; for many years no material was found to be superconducting above 23 K.

More recently, novel materials have been found to be superconducting below 90 K, critical temperatures as high as 160K have been reported.

18-10 Electrical Conduction in the Human Nervous System

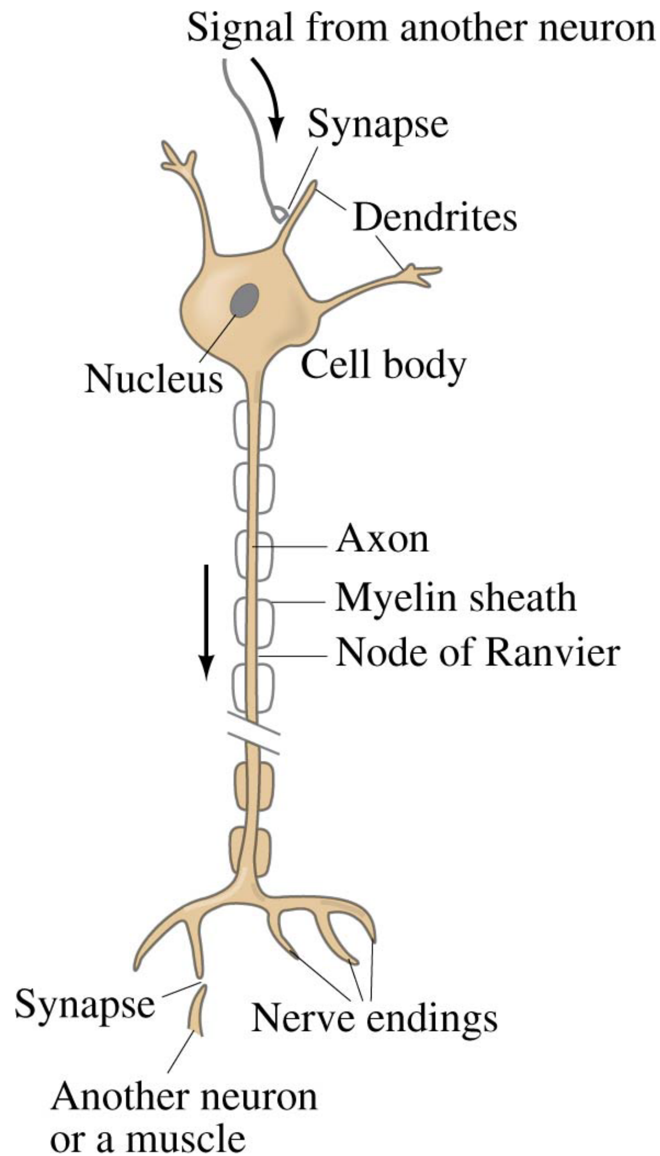
The human nervous system depends on the flow of electric charge.

The basic elements of the nervous system are cells called neurons.

Neurons have a main cell body, small attachments called dendrites, and a long tail called the axon.

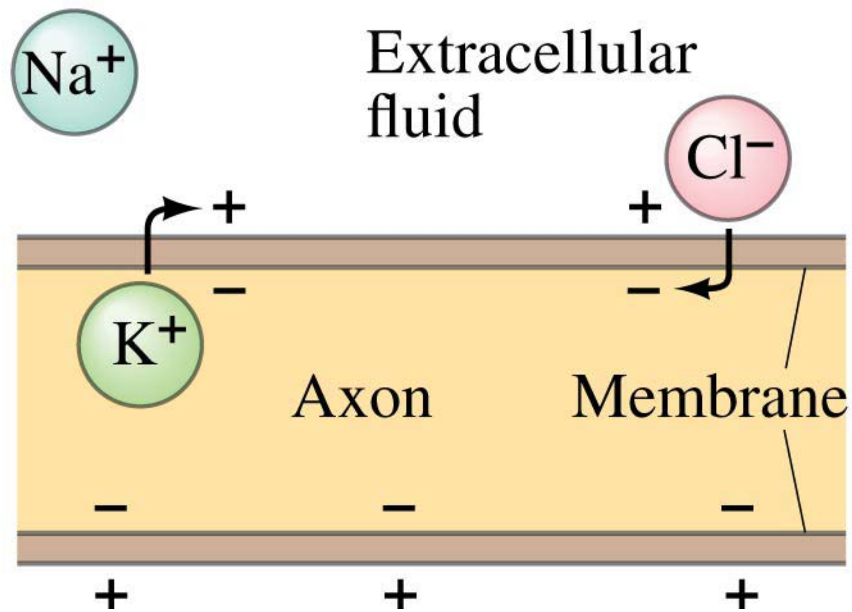
18-10 Electrical Conduction in the Human Nervous System

Signals are received by the dendrites, propagated along the axon, and transmitted through a connection called a synapse.



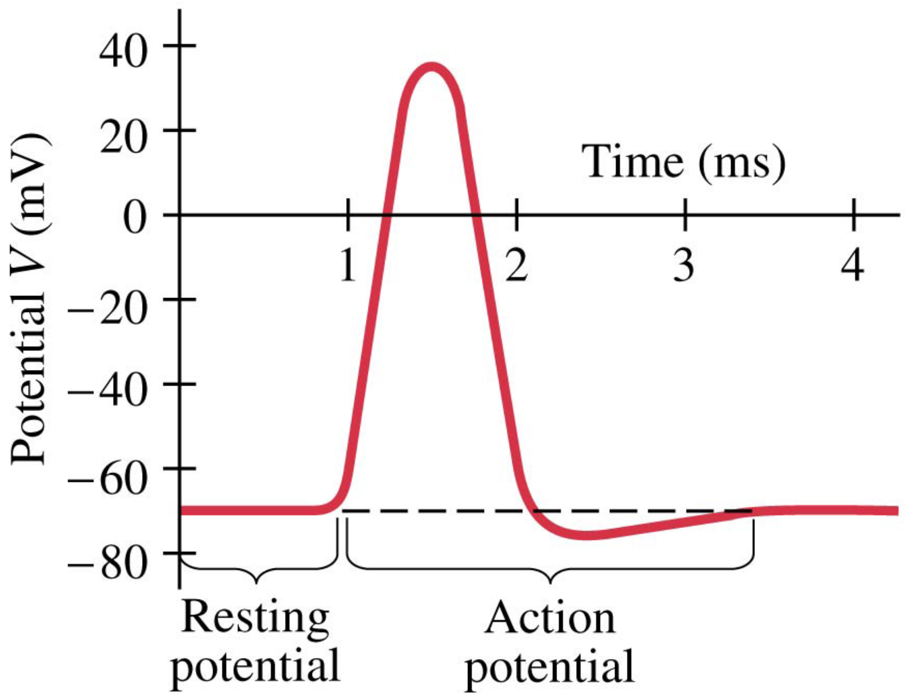
18-10 Electrical Conduction in the Human Nervous System

This process depends on there being a dipole layer of charge on the cell membrane, and different concentrations of ions inside and outside the cell.



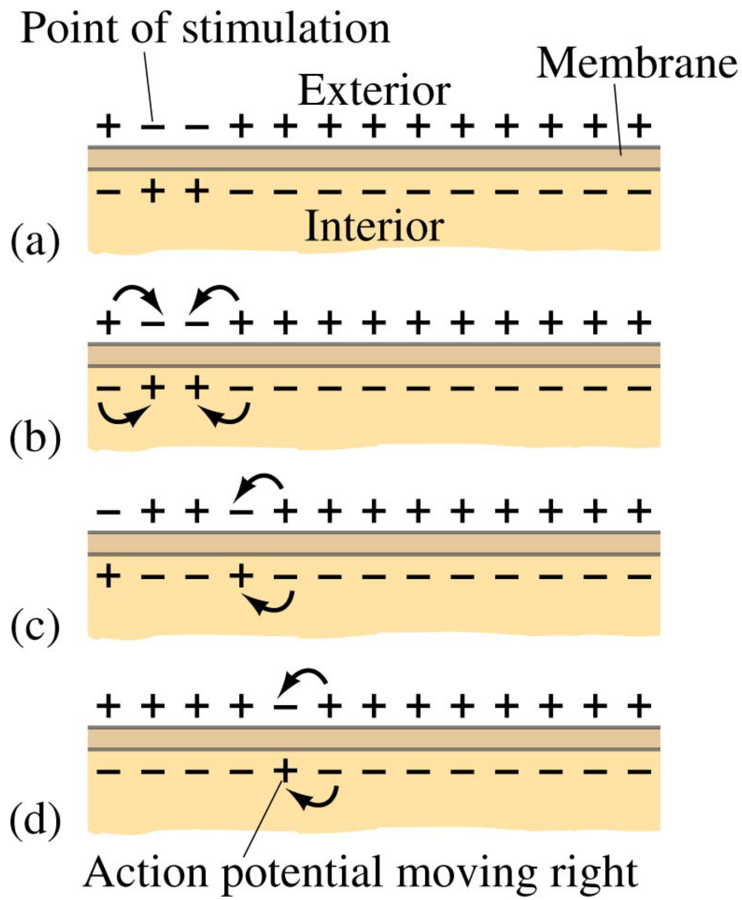
18-10 Electrical Conduction in the Human Nervous System

This applies to most cells in the body. Neurons can respond to a stimulus and conduct an electrical signal. This signal is in the form of an action potential.



18-10 Electrical Conduction in the Human Nervous System

The action potential propagates along the axon membrane.



Summary of Chapter 18

- A battery is a source of constant potential difference.
- Electric current is the rate of flow of electric charge.
- Conventional current is in the direction that positive charge would flow.
- Resistance is the ratio of voltage to current: $V = IR.$

Summary of Chapter 18

- Ohmic materials have constant resistance, independent of voltage.
- Resistance is determined by shape and material: $R = \rho \frac{\ell}{A}$
- ρ is the resistivity.
- Power in an electric circuit: $P = IV.$

Summary of Chapter 18

- Direct current is constant
- Alternating current varies sinusoidally

$$I = \frac{V}{R} = \frac{V_0}{R}\sin\omega t = I_0 \sin\omega t$$

- The average (rms) current and voltage:

$$I_{\rm rms} = \sqrt{\overline{I^2}} = \frac{I_0}{\sqrt{2}} = 0.707\, I_0$$

$$V_{\rm rms} = \sqrt{\overline{V^2}} = \frac{V_0}{\sqrt{2}} = 0.707\, V_0$$

- The average (rms) current and voltage:

$$I = \frac{\Delta Q}{\Delta t} = neAv_{\rm d}$$