Chapter 26

Current and Resistance

Electric Current

Most practical applications of electricity deal with electric currents.

- The electric charges move through some region of space.

The *resistor* is a new element added to circuits.

Energy can be transferred to a device in an electric circuit.

The energy transfer mechanism is electrical transmission, T_{ET}.

Electric Current

Electric current is the rate of flow of charge through some region of space.

The SI unit of current is the **ampere** (A).

- $1\ \mathrm{A} = 1\ \mathrm{C/s}$

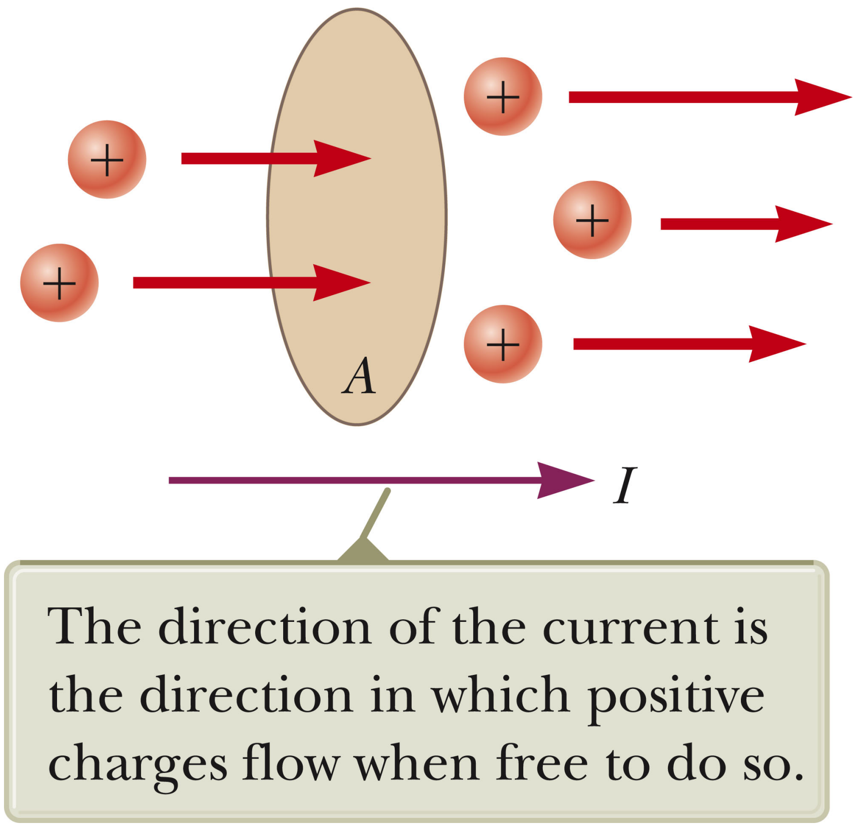
The symbol for electric current is I.

Average Electric Current

Assume charges are moving perpendicular to a surface of area A.

If ΔQ is the amount of charge that passes through A in time Δt, then the average current is

$$I_{avg} = \frac{\Delta Q}{\Delta t}$$



Instantaneous Electric Current

If the rate at which the charge flows varies with time, the instantaneous current, I, is defined as the differential limit of average current as $\Delta t \to 0$.

$$I \equiv \frac{dQ}{dt}$$

Direction of Current

The charged particles passing through the surface could be positive, negative or both.

It is conventional to assign to the current the same direction as the flow of positive charges.

In an ordinary conductor, the direction of current flow is opposite the direction of the flow of electrons.

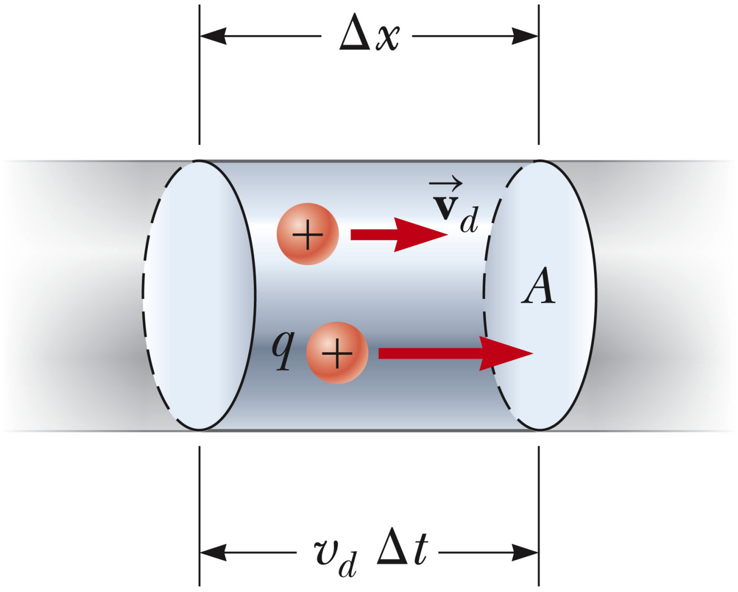
It is common to refer to any moving charge as a *charge carrier.*

Current and Drift Speed

Charged particles move through a cylindrical conductor of cross-sectional area A.

n is the number of mobile charge carriers per unit volume.

$nA\Delta x$ is the total number of charge carriers in a segment.



Current and Drift Speed, cont

The total charge is the number of carriers times the charge per carrier, q.

- $\Delta Q = (nA\Delta x)q$
- Assume the carriers move with a velocity parallel to the axis of the cylinder such that they experience a displacement in the x-direction.

If v_d is the speed at which the carriers move, then

- $v_d = \Delta x / \Delta t$ and $\Delta x = v_d \Delta t$

Rewritten: $\Delta Q = (nAv_d\Delta t)q$

Finally, current, $I_{\text{ave}} = \Delta Q / \Delta t = nqv_dA$

v_d is an average speed called the **drift speed.**

Charge Carrier Motion in a Conductor

When a potential difference is applied across the conductor, an electric field is set up in the conductor which exerts an electric force on the electrons.

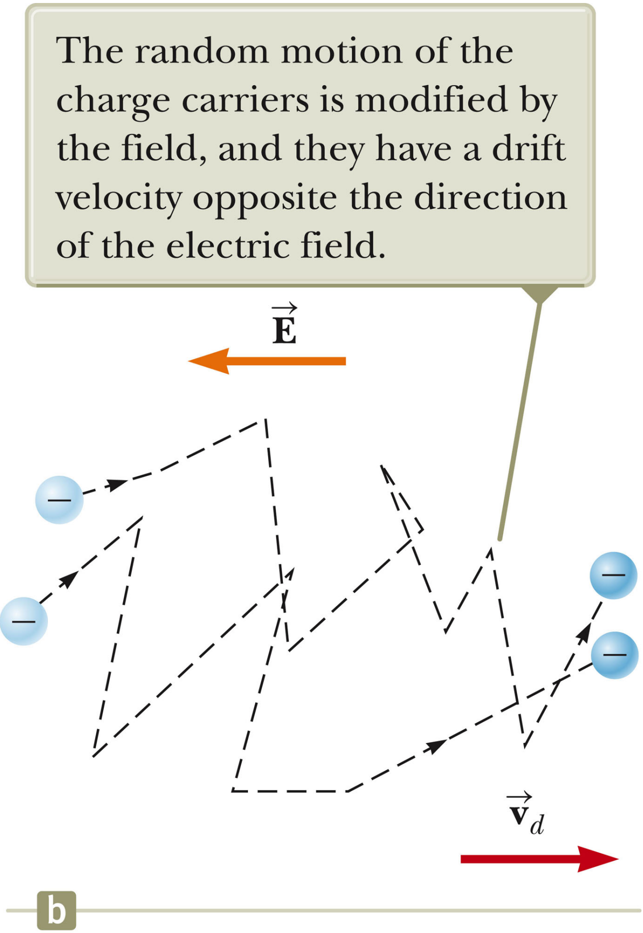
The motion of the electrons is no longer random.

The zigzag black lines represents the motion of a charge carrier in a conductor in the presence of an electric field.

- The net drift speed is small.

The sharp changes in direction are due to collisions.

The net motion of electrons is opposite the direction of the electric field.



Motion of Charge Carriers, cont.

In the presence of an electric field, in spite of all the collisions, the charge carriers slowly move along the conductor with a drift velocity,

$$\vec{\mathbf{v}}_d$$

The electric field exerts forces on the conduction electrons in the wire.

These forces cause the electrons to move in the wire and create a current.

Motion of Charge Carriers, final

The electrons are already in the wire.

They respond to the electric field set up by the battery.

The battery does not supply the electrons, it only establishes the electric field.

Example 26.01: Drift Speed in a Copper Wire

The 12-gauge copper wire in a typical residential building has a cross-sectional area of $3.31 \times 10^{-6}\ \mathrm{m}^2$. It carries a constant current of $10.0\ \mathrm{A}$. What is the drift speed of the electrons in the wire? Assume each copper atom contributes one free electron to the current. The density of copper is $8.92\ \mathrm{g/cm}^3$.

The molar mass of copper is $M = 63.5\ \mathrm{g/mol}$. 1 mol of any substance contains Avogadro's number of atoms $\left(N_\mathrm{A} = 6.02 \times 10^{23}\ \mathrm{mol}^{-1}\right)$.

$$n = \frac{N_\mathrm{A}\rho}{M}$$

$$v_d = \frac{I_\mathrm{avg}}{nqA} = \frac{I}{nqA} = \frac{IM}{qAN_\mathrm{A}\rho}$$

$$v_d = \frac{(10.0\ \mathrm{A})(0.0635\ \mathrm{kg/mol})}{\left(1.60 \times 10^{-19}\mathrm{C}\right)\left(3.31 \times 10^{-6}\ \mathrm{m}^2\right)\left(6.02 \times 10^{23}\ \mathrm{mol}^{-1}\right)\left(8920\ \mathrm{kg/m}^3\right)}$$

$$= 2.23 \times 10^{-4}\ \mathrm{m/s}$$

Problem 26.04:

A copper wire has a circular cross section with a radius of 1.25 mm . (a) If the wire carries a current of 3.70 A, find the drift speed of the electrons in this wire. (b) All other things being equal, what happens to the drift speed in wires made of metal having a larger number of conduction electrons per atom than copper? Explain.

(a) From Example 26.1 in the textbook, the density of charge carriers (electrons) in a copper wire is $n = 8.46 \times 10^{28}$ electrons $/\text{m}^3$. With $A = \pi r^2$ and $|q| = e$, the drift speed of electrons in this wire is

$$v_d = \frac{I}{n|q|A} = \frac{I}{ne\left(\pi r^2\right)}$$

$$= \frac{3.70\text{C/s}}{\left(8.46 \times 10^{28} \text{ m}^{-3}\right)\left(1.60 \times 10^{-19}\text{C}\right)\pi\left(1.25 \times 10^{-3} \text{ m}\right)^2}$$

$$= 5.57 \times 10^{-5} \text{ m/s}$$

(b) The drift speed is smaller because more electrons are being conducted. To create the same current, therefore, the drift speed need not be as great.

Current Density

J is the **current density** of a conductor.

It is defined as the current per unit area.

- $J \equiv I/A = nqv_d$
- This expression is valid only if the current density is uniform and A is perpendicular to the direction of the current.

J has SI units of $\mathrm{A/m^2}$

The current density is in the direction of the positive charge carriers.

Problem 26.06:

The figure represents a section of a conductor of nonuniform diameter carrying a current of $I = 5.00\ \text{A}$. The radius of cross-section A_1 is $r_1 = 0.400\ \text{cm}$. (a) What is the magnitude of the current density across A_1 ? The radius r_2 at A_2 is larger than the radius r_1 at A_1. (b) Is the current at A_2 larger, smaller, or the same? (c) Is the current density at A_2 larger, smaller, or the same? Assume $A_2 = 4A_1$. Specify the (d) radius, (e) current, and (f) current density at A_2.

(a) $J = \frac{I}{A} = \frac{5.00\ \text{A}}{\pi\left(4.00 \times 10^{-3}\ \text{m}\right)^2} = 99.5\text{kA/m}^2$

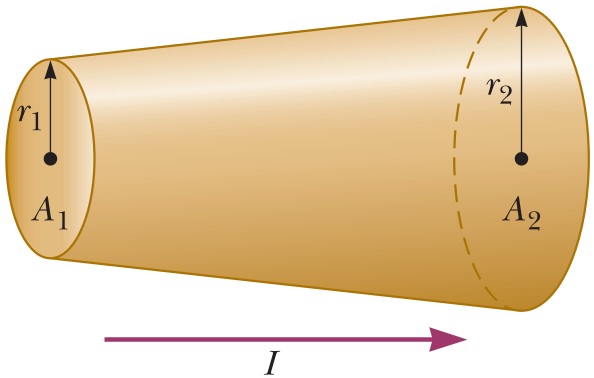
(b) Current is the same.

(c) The cross-sectional area is greater; therefore the current density is smaller.

(d) $A_2 = 4A_1$ or $\pi r_2^2 = 4\pi r_1^2$ so
$r_2 = 2r_1 = 0.800\ \text{cm}.$

(e) $I = 5.00\ \text{A}$

(f)
$J_2 = \frac{1}{4} J_1 = \frac{1}{4}\left(9.95 \times 10^4\ \text{A/m}^2\right) = 2.49 \times 10^4\ \text{A/m}^2$



Conductivity

A current density and an electric field are established in a conductor whenever a potential difference is maintained across the conductor.

For some materials, the current density is directly proportional to the field.

The constant of proportionality, σ, is called the **conductivity** of the conductor.

Ohm's Law

Ohm's law states that for many materials, the ratio of the current density to the electric field is a constant σ that is independent of the electric field producing the current.

- Most metals obey Ohm's law
- Mathematically, $J = \sigma E$
- Materials that obey Ohm's law are said to be *ohmic*
- Not all materials follow Ohm's law
  - Materials that do not obey Ohm's law are said to be *nonohmic.*

Ohm's law is not a fundamental law of nature.

Ohm's law is an empirical relationship valid only for certain materials.

Georg Simon Ohm

1789 -1854

German physicist

Formulated idea of resistance

Discovered the proportionalities now known as forms of Ohm's Law

Resistance

In a conductor, the voltage applied across the ends of the conductor is proportional to the current through the conductor.

The constant of proportionality is called the **resistance** of the conductor.

$$R \equiv \frac{\Delta V}{I}$$

SI units of resistance are *ohms* (Ω).

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

Resistance in a circuit arises due to collisions between the electrons carrying the current with the fixed atoms inside the conductor.

Resistors

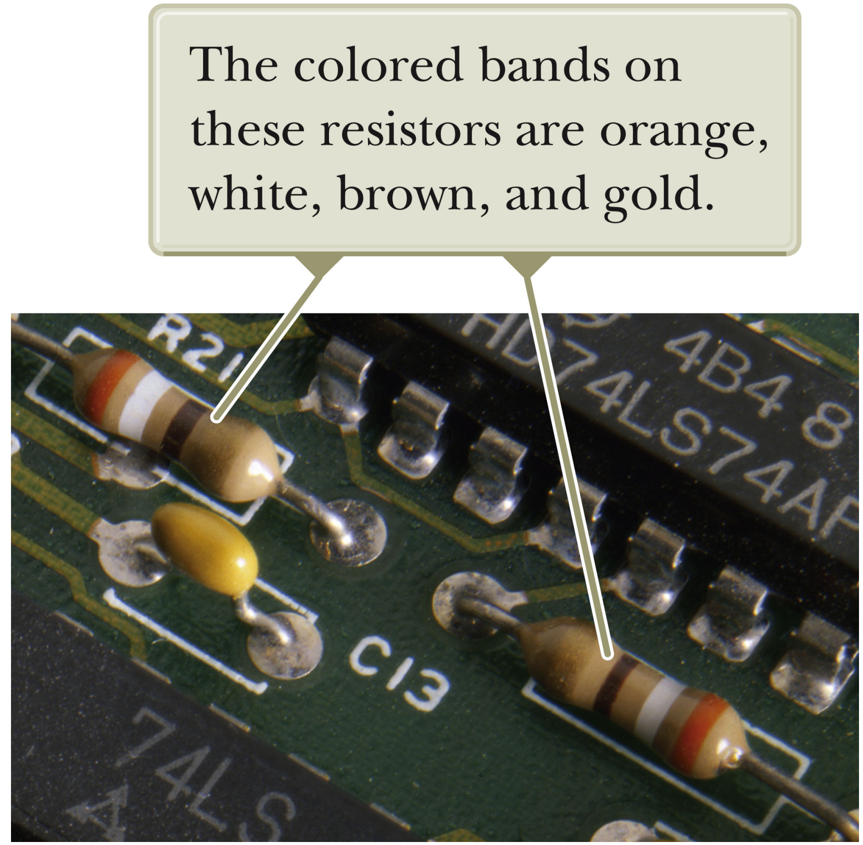
Most electric circuits use circuit elements called **resistors** to control the current in the various parts of the circuit.

Stand-alone resistors are widely used.

- Resistors can be built into integrated circuit chips.

Values of resistors are normally indicated by colored bands.

- The first two bands give the first two digits in the resistance value.
- The third band represents the power of ten for the multiplier band.
- The last band is the tolerance.



Resistor Color Codes

TABLE 26.1 Color Coding for Resistors

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%
Colorless			20%

Resistor Color Code Example

Red (=2) and blue (=6) give the first two digits: 26

Green (=5) gives the power of ten in the multiplier: 10^5

The value of the resistor then is $26 \times 10^5\ \Omega$ (or 2.6 MΩ)

The tolerance is 10% (silver = 10%) or $2.6 \times 10^5\ \Omega$

Resistivity

The inverse of the conductivity is the **resistivity**:

- $\rho = 1/\sigma$

Resistivity has SI units of ohm-meters ($\Omega \cdot \mathrm{m}$)

Resistance is also related to resistivity:

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

Resistivity Values

TABLE 26.2 Resistivities and Temperature Coefficients of Resistivity for Various Materials

Material	Resistivity[a] ($\Omega \cdot m$)	Temperature Coefficient[b] α $[(°C)^{-1}]$
Silver	1.59×10^{-8}	3.8×10^{-3}
Copper	1.7×10^{-8}	3.9×10^{-3}
Gold	2.44×10^{-8}	3.4×10^{-3}
Aluminum	2.82×10^{-8}	3.9×10^{-3}
Tungsten	5.6×10^{-8}	4.5×10^{-3}
Iron	10×10^{-8}	5.0×10^{-3}
Platinum	11×10^{-8}	3.92×10^{-3}
Lead	22×10^{-8}	3.9×10^{-3}
Nichrome[c]	1.00×10^{-6}	0.4×10^{-3}
Carbon	3.5×10^{-5}	-0.5×10^{-3}
Germanium	0.46	-48×10^{-3}
Silicon[d]	2.3×10^{3}	-75×10^{-3}
Glass	10^{10} to 10^{14}	
Hard rubber	$\sim 10^{13}$	
Sulfur	10^{15}	
Quartz (fused)	75×10^{16}	

[a] All values at 20°C. All elements in this table are assumed to be free of impurities.
[b] See Section 26.4.
[c] A nickel–chromium alloy commonly used in heating elements. The resistivity of Nichrome varies with composition and ranges between 1.00×10^{-6} and 1.50×10^{-6} $\Omega \cdot m$.
[d] The resistivity of silicon is very sensitive to purity. The value can be changed by several orders of magnitude when it is doped with other atoms.

Resistance and Resistivity, Summary

Every ohmic material has a characteristic resistivity that depends on the properties of the material and on temperature.

- Resistivity is a property of substances.

The resistance of a material depends on its geometry and its resistivity.

- Resistance is a property of an object.

An ideal conductor would have zero resistivity.

An ideal insulator would have infinite resistivity.

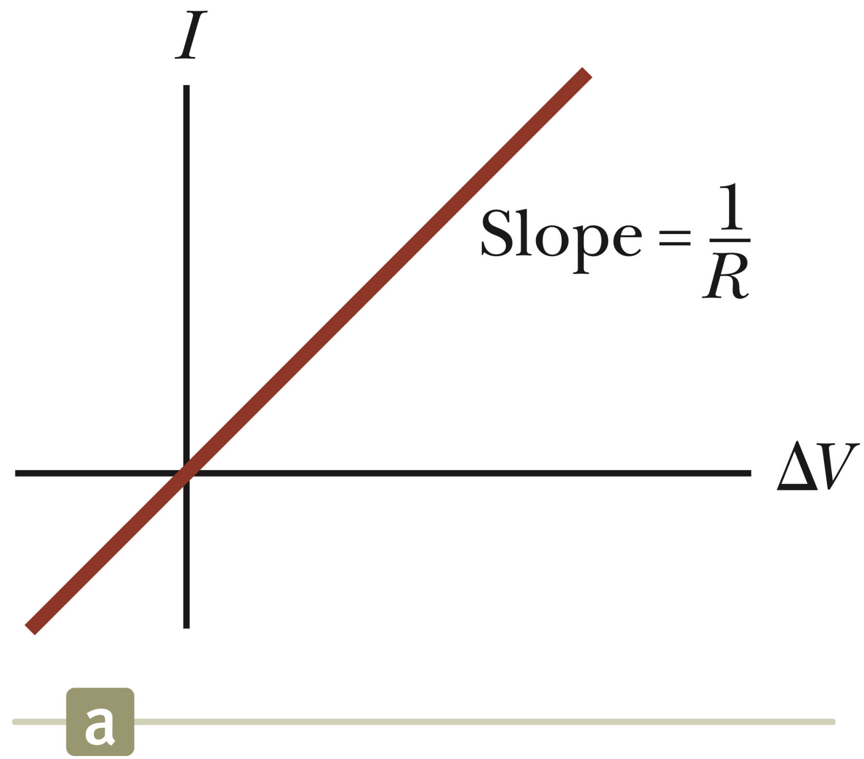
Ohmic Material, Graph

An ohmic device

The resistance is constant over a wide range of voltages.

The relationship between current and voltage is linear.

The slope is related to the resistance.

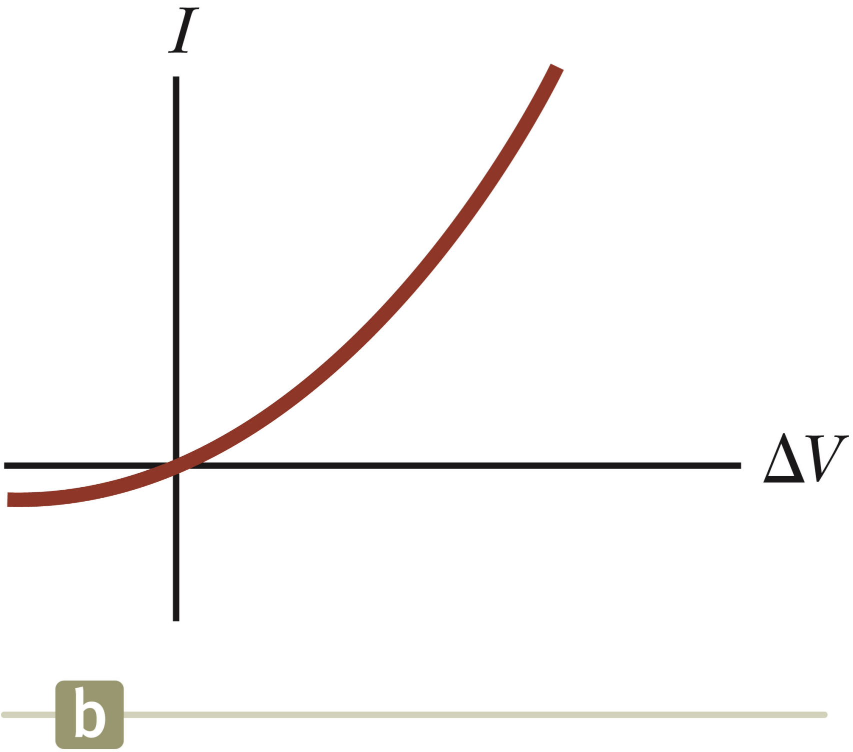


Nonohmic Material, Graph

Nonohmic materials are those whose resistance changes with voltage or current.

The current-voltage relationship is nonlinear.

A junction diode is a common example of a nonohmic device.



Example 26.02: The Resistance of Nichrome Wire

The radius of 22-gauge Nichrome wire is 0.32 mm .

(A) Calculate the resistance per unit length of this wire.

(B) If a potential difference of 10 V is maintained across a $1.0 - \text{m}$ length of the Nichrome wire, what is the current in the wire?

(A) $\frac{R}{\ell} = \frac{\rho}{A} = \frac{\rho}{\pi r^2} = \frac{1.0 \times 10^{-6} \Omega \cdot \text{m}}{\pi \left(0.32 \times 10^{-3} \text{ m}\right)^2} = 3.1 \Omega/\text{m}$

(B) $I = \frac{\Delta V}{R} = \frac{\Delta V}{(R/\ell)\ell} = \frac{10 \text{ V}}{(3.1 \Omega/\text{m})(1.0 \text{ m})} = 3.2 \text{ A}$

Problem 26.10:

A wire 50.0 m long and 2.00 mm in diameter is connected to a source with a potential difference of 9.11 V , and the current is found to be 36.0 A . Assume a temperature of 20.0°C and, using Table 26.2, identify the metal out of which the wire is made.

From Ohm's law, $R = \Delta V / I$, and

$$R = \rho \ell / A = \rho \ell / \left(\pi d^2 / 4 \right)$$

Solving for the resistivity gives

$$\rho = \left(\frac{\pi d^2}{4\ell} \right) R = \left(\frac{\pi d^2}{4\ell} \right) \left(\frac{\Delta V}{I} \right) = \left[\frac{\pi \left(2.00 \times 10^{-3} \text{ m} \right)^2}{4(50.0 \text{ m})} \right] \left(\frac{9.11 \text{ V}}{36.0 \text{ A}} \right)$$

$$= 1.59 \times 10^{-8} \Omega \cdot \text{ m}$$

Then, from Table 26.2, we see that the wire is made of silver.

Problem 26.13:

Suppose you wish to fabricate a uniform wire from $1.00\,g$ of copper. If the wire is to have a resistance of $R = 0.5\,\Omega$ and all the copper is to be used, what must be (a) the length and (b) the diameter of this wire?

(a) Given total mass $m = \rho_m V = \rho_m A\ell \quad \rightarrow \quad A = \frac{m}{\rho_m \ell}$, where $\rho_m \equiv$ mass density.

Taking $\rho \equiv$ resistivity, $R = \frac{\rho\ell}{A} = \frac{\rho\ell}{m/\rho_m\ell} = \frac{\rho\rho_m\ell^2}{m}$.
Thus,

$$\ell = \sqrt{\frac{mR}{\rho\rho_m}} = \sqrt{\frac{\left(1.00 \times 10^{-3}\ \mathrm{kg}\right)(0.500\Omega)}{\left(1.70 \times 10^{-8}\Omega \cdot\ \mathrm{m}\right)\left(8.92 \times 10^{3}\ \mathrm{kg/m^3}\right)}}$$

$$= 1.82\ \mathrm{m}$$

(b) $\quad V = \frac{m}{\rho_m}$, or $\pi r^2 \ell = \frac{m}{\rho_m}$

Thus,

$$r = \sqrt{\frac{m}{\pi\rho_m\ell}} = \sqrt{\frac{1.00 \times 10^{-3}\ \mathrm{kg}}{\pi\left(8.92 \times 10^{3}\ \mathrm{kg/m^3}\right)(1.82\ \mathrm{m})}} = 1.40 \times 10^{-4}\ \mathrm{m}$$

The diameter is twice this distance: diameter $= 280\mu\ \mathrm{m}$

Resistance and Temperature

Over a limited temperature range, the resistivity of a conductor varies approximately linearly with the temperature.

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

- ρ_o is the resistivity at some reference temperature T_o
  - T_o is usually taken to be $20^\circ \mathrm{C}$
  - α is the **temperature coefficient of resistivity**
    - SI units of α are $^\circ\mathrm{C}^{-1}$

The temperature coefficient of resistivity can be expressed as

$$\alpha = \frac{\Delta\rho/\rho_0}{\Delta T}$$

Temperature Variation of Resistance

Since the resistance of a conductor with uniform cross sectional area is proportional to the resistivity, you can find the effect of temperature on resistance.

$$R = R_0 \left[1 + \alpha \left(T - T_0\right)\right]$$

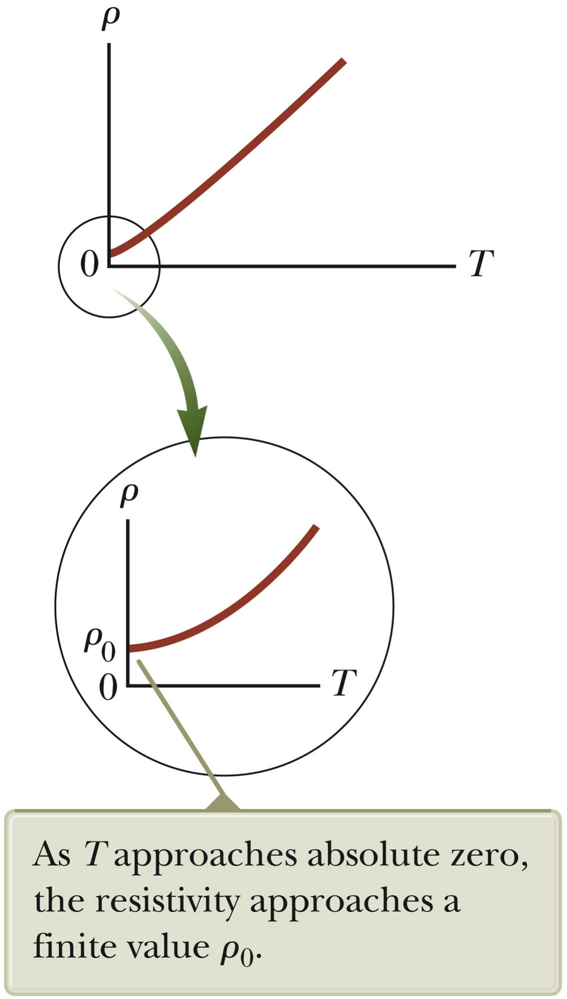
Use of this property enables precise temperature measurements through careful monitoring of the resistance of a probe made from a particular material.

Resistivity and Temperature, Graphical View

For some metals, the resistivity is nearly proportional to the temperature.

A nonlinear region always exists at very low temperatures.

The resistivity usually reaches some finite value as the temperature approaches absolute zero.



Residual Resistivity

The residual resistivity near absolute zero is caused primarily by the collisions of electrons with impurities and imperfections in the metal.

High temperature resistivity is predominantly characterized by collisions between the electrons and the metal atoms.

- This is the linear range on the graph.

Semiconductors

Semiconductors are materials that exhibit a decrease in resistivity with an increase in temperature.

α is negative

There is an increase in the density of charge carriers at higher temperatures.

Problem 26.17:

What is the fractional change in the resistance of an iron filament when its temperature changes from $25.0^{\circ}\mathrm{C}$ to $50.0^{\circ}\mathrm{C}$?

$$\frac{\Delta R}{R_0} = \alpha \Delta T = \left(5.00 \times 10^{-3} {}^{\circ}\mathrm{C}^{-1}\right)\left(50.0^{\circ}\mathrm{C} - 25.0^{\circ}\mathrm{C}\right) = 0.12$$

Problem 26.18:

A certain lightbulb has a tungsten filament with a resistance of 19.0Ω when at $20.0^\circ\mathrm{C}$ and 140Ω when hot. Assume the resistivity of tungsten varies linearly with temperature even over the large temperature range involved here. Find the temperature of the hot filament.

$R = R_0[1 + \alpha(\Delta T)]$ gives

$$140\Omega = (19.0\Omega)\left[1 + \left(4.50 \times 10^{-3}/^\circ\mathrm{C}\right)\Delta T\right]$$

Solving,

$$\Delta T = 1.42 \times 10^{3\circ}\mathrm{C} = T - 20.0^\circ\mathrm{C}$$

And the final temperature is

$$T = 1.44 \times 10^{3\circ}\mathrm{C}$$

Electrical Power

Assume a circuit as shown

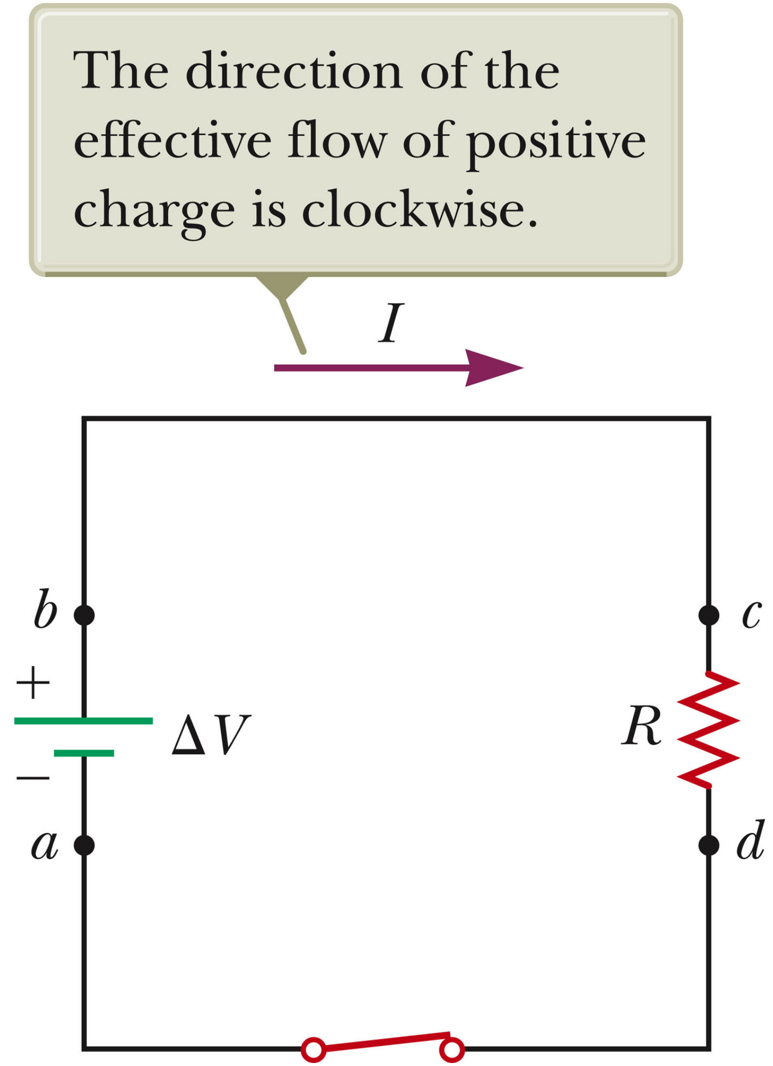
The entire circuit is the system.

As a charge moves from a to b, the electric potential energy of the system increases by $Q\Delta V$.

- The chemical energy in the battery must decrease by this same amount.

This electric potential energy is transformed into internal energy in the resistor.

- Corresponds to increased vibrational motion of the atoms in the resistor



Electric Power, 2

The resistor is normally in contact with the air, so its increased temperature will result in a transfer of energy by heat into the air.

The resistor also emits thermal radiation.

After some time interval, the resistor reaches a constant temperature.

- The input of energy from the battery is balanced by the output of energy by heat and radiation.

The rate at which the system's potential energy decreases as the charge passes through the resistor is equal to the rate at which the system gains internal energy in the resistor.

The **power** is the rate at which the energy is delivered to the resistor.

Electric Power, final

The power is given by the equation $P = I\Delta V$.

Applying Ohm's Law, alternative expressions can be found:

$$P = I^2 R = \frac{(\Delta V)^2}{R}$$

Units: I is in A, R is in Ω, ΔV is in V, and P is in W.

Some Final Notes About Current

A single electron is moving at the drift velocity in the circuit.

- It may take hours for an electron to move completely around a circuit.

The current is the same everywhere in the circuit.

- Current is not “used up” anywhere in the circuit

The charges flow in the same rotational sense at all points in the circuit.

Electric Power Transmission

Real power lines have resistance.

Power companies transmit electricity at high voltages and low currents to minimize power losses.

Section 26.6

Example 26.04: Power in an Electric Heater

An electric heater is constructed by applying a potential difference of $120\ \mathrm{V}$ across a Nichrome wire that has a total resistance of $8.00\ \Omega$. Find the current carried by the wire and the power rating of the heater.

$$I = \frac{\Delta V}{R} = \frac{120\ \mathrm{V}}{8.00 \Omega} = 15.0\ \mathrm{A}$$

$$P = I^2 R = (15.0\ \mathrm{A})^2 (8.00 \Omega) = 1.80 \times 10^3\ \mathrm{W} = 1.80\ \mathrm{kW}$$

Example 26.05: Linking Electricity and Thermodynamics

An immersion heater must increase the temperature of $1.50\,\mathrm{kg}$ of water from $10.0^\circ\mathrm{C}$ to $50.0^\circ\mathrm{C}$ in 10.0 min while operating at $110\,\mathrm{V}$.

(A) What is the required resistance of the heater?

(B) Estimate the cost of heating the water.

(A)

$$P = \frac{(\Delta V)^2}{R} = \frac{Q}{\Delta t}$$

$$\frac{(\Delta V)^2}{R} = \frac{mc\Delta T}{\Delta t} \rightarrow R = \frac{(\Delta V)^2 \Delta t}{mc\Delta T}$$

$$R = \frac{(110\ \mathrm{V})^2(600\ \mathrm{s})}{(1.50\ \mathrm{kg})\left(4186\ \mathrm{J/kg}\cdot{}^\circ\mathrm{C}\right)\left(50.0^\circ\mathrm{C} - 10.0^\circ\mathrm{C}\right)} = 28.9\Omega$$

(B)

$$T_{\mathrm{ET}} = P\Delta t = \frac{(\Delta V)^2}{R}\Delta t = \frac{(110\ \mathrm{V})^2}{28.9\Omega}(10.0\ \mathrm{min})\left(\frac{1\ \mathrm{h}}{60.0\ \mathrm{min}}\right)$$

$$= 69.8\ \mathrm{Wh} = 0.0698\mathrm{kWh}$$

Cost $= (0.0698\mathrm{kWh})(\$0.11/\mathrm{kWh}) = \$0.008$

Problem 26.23:

Assume that global lightning on the Earth constitutes a constant current of $1.00\,\mathrm{kA}$ between the ground and an atmospheric layer at potential $300\,\mathrm{kV}$. (a) Find the power of terrestrial lightning. (b) For comparison, find the power of sunlight falling on the Earth. Sunlight has an intensity of $1370\ \mathrm{W/m^2}$ above the atmosphere. Sunlight falls perpendicularly on the circular projected area that the Earth presents to the Sun.

(a) $P = (\Delta V)I = \left(300 \times 10^3\ \mathrm{J/C}\right)\left(1.00 \times 10^3 \mathrm{C/s}\right) = 3.00 \times 10^8\ \mathrm{W}$

A large electric generating station, fed by a trainload of coal each day, converts energy faster.

(b) $I = \frac{P}{A} = \frac{P}{\pi r^2}$

$$P = I\left(\pi r^2\right) = \left(1370\ \mathrm{W/m^2}\right)\left[\pi\left(6.37 \times 10^6\ \mathrm{m}\right)^2\right] = 1.75 \times 10^{17}\ \mathrm{W}$$

Terrestrial solar power is immense compared to lightning and compared to all human energy conversions.

Problem 26.28:

Residential building codes typically require the use of 12-gauge copper wire (diameter 0.205 cm) for wiring receptacles. Such circuits carry currents as large as 20.0 A . If a wire of smaller diameter (with a higher gauge number) carried that much current, the wire could rise to a high temperature and cause a fire. (a) Calculate the rate at which internal energy is produced in 1.00 m of 12-gauge copper wire carrying 20.0 A . (b) What If? Repeat the calculation for a 12-gauge aluminum wire. (c) Explain whether a 12-gauge aluminum wire would be as safe as a copper wire.

(a) The resistance of 1.00 m of 12-gauge copper wire is

$$R = \frac{\rho \ell}{A} = \frac{\rho \ell}{\pi (d/2)^2} = \frac{4\rho \ell}{\pi d^2} = \frac{4\left(1.7 \times 10^{-8} \Omega \cdot \text{ m}\right)(1.00 \text{ m})}{\pi \left(0.205 \times 10^{-2} \text{ m}\right)^2}$$

$$= 5.2 \times 10^{-3} \Omega$$

The rate of internal energy production is

$$P = I\Delta V = I^2 R = (20.0 \text{ A})^2 \left(5.2 \times 10^{-3} \Omega\right) = 2.1 \text{ W}$$

(b) $$R = \frac{4\rho \ell}{\pi d^2} = \frac{4\left(2.82 \times 10^{-8} \Omega \cdot \text{m}\right)(1.00 \text{ m})}{\pi\left(0.205 \times 10^{-2} \text{ m}\right)^2} = 8.54 \times 10^{-3} \Omega$$

$$P = I\Delta V = I^2 R = (20.0 \text{ A})^2 \left(8.54 \times 10^{-3} \Omega\right) = 3.42 \text{ W}$$

(c) It would not be as safe. If surrounded by thermal insulation, it would get much hotter than a copper wire.

Problem 26.30:

An 11.0-W energy-efficient fluorescent lightbulb is designed to produce the same illumination as a conventional $40.0-\mathrm{W}$ incandescent lightbulb. Assuming a cost of $\$0.110/\mathrm{kWh}$ for energy from the electric company, how much money does the user of the energy-efficient bulb save during $100\,\mathrm{h}$ of use?

The energy taken in by electric transmission for the fluorescent bulb is

$$P\Delta t = 11\ \mathrm{J/s}(100\ \mathrm{h})\left(\frac{3600\ \mathrm{s}}{1\ \mathrm{h}}\right) = 3.96\times 10^{6}\ \mathrm{J}$$

$$\text{cost} = 3.96\times 10^{6}\ \mathrm{J}\left(\frac{\$0.110}{\mathrm{kWh}}\right)\left(\frac{\mathrm{k}}{1000}\right)\left(\frac{\mathrm{W}\cdot\mathrm{s}}{\mathrm{J}}\right)\left(\frac{\mathrm{h}}{3600\ \mathrm{s}}\right) = \$0.121$$

For the incandescent bulb,

$$P\Delta t = 40\ \mathrm{W}(100\ \mathrm{h})\left(\frac{3600\ \mathrm{s}}{1\ \mathrm{h}}\right) = 1.44\times 10^{7}\ \mathrm{J}$$

$$\text{cost} = 1.44\times 10^{7}\ \mathrm{J}\left(\frac{\$0.110}{3.6\times 10^{6}\ \mathrm{J}}\right) = \$0.440$$

$$\text{savings} = \$0.440 - \$0.121 = \$0.319$$

Problem 26.35:

One wire in a high-voltage transmission line carries 1000 A starting at 700 kV for a distance of 100 mi. If the resistance in the wire is $0.500\Omega/\text{mi}$, what is the power loss due to the resistance of the wire?

The resistance of one wire is $\left(\frac{0.500\Omega}{\text{mi}}\right)(100\text{mi}) = 50.0\Omega$.

The whole wire is at nominal 700 kV away from ground potential, but the potential difference between its two ends is

$$IR = (1000\ \text{A})(50.0\Omega) = 50.0\text{kV}$$

Then it radiates as heat power

$$P = I\Delta V = (1000\ \text{A})\left(50.0\times 10^3\ \text{V}\right) = 50.0\text{MW}$$