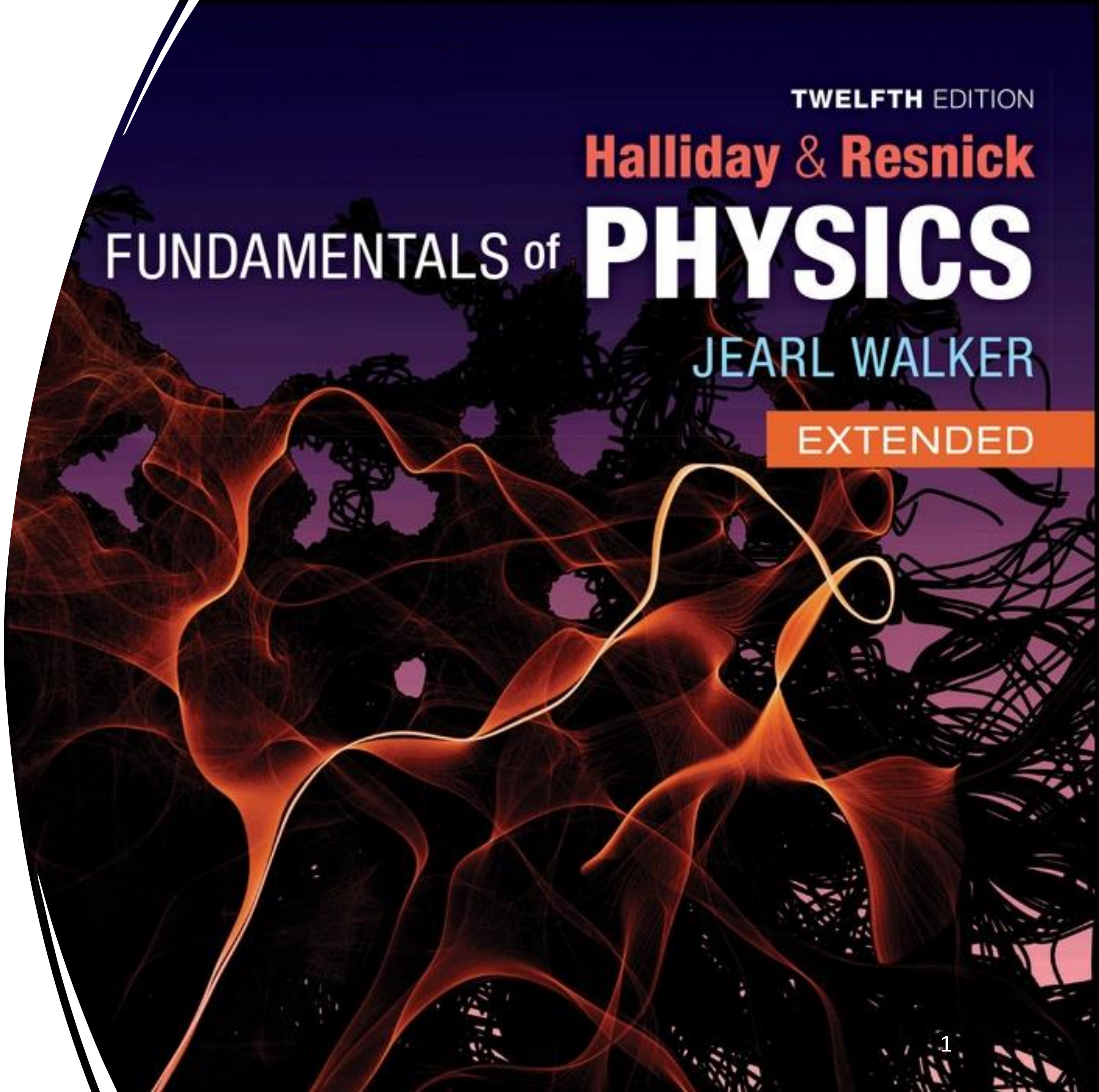
Tue 17 Feb

Chapter 26

Current and Resistance

***Fundamentals of Physics*, Twelfth Edition. Halliday & Resnick, Walker**



(مولد)
Generater: give electricity → battery
• Windmills

chemical energy → electricity

motor : use electricity to convert into

conductors: free electrons

$E_{inside} = 0$

Already took these concepts in the lab

Chapter 26 Current and Resistance

Section 26.1 Electric Current

Conductive Loop with No Voltage Source

Figure (a) shows an isolated conducting loop. Even if the conductive loop has excess charge, it is all at the same potential. No electric field can exist within it or along its surface.

Figure (a)

Conductive Loop with a Voltage Source

If we insert a battery in the loop, as in Figure (b), the conducting loop is no longer at a single potential. Electric fields act inside the material making up the loop, exerting forces on internal charges, causing them to move and thus establishing a **current**. (The diagram assumes the motion of positive charges moving clockwise.)

Electric field to left
Force to right

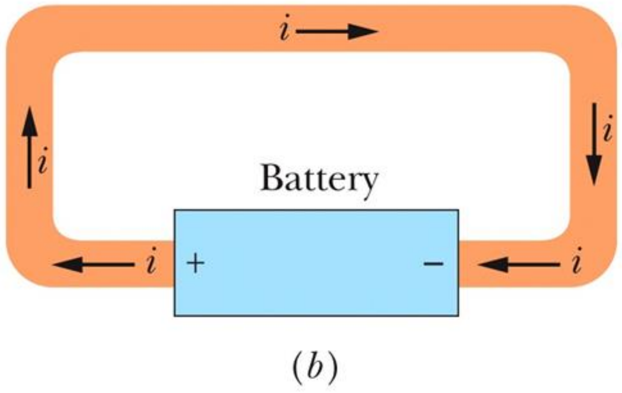


Figure (b)

Electric Current: Definition

Figure (c) shows a section of a conductor, part of a conducting loop in which current has been established. If charge *dq* passes through a hypothetical plane (such as aa') in time *dt*, then the current *i* through that plane is defined as:

Current = no. of charges / time

$$i = \frac{dq}{dt} \quad \text{(definition of current)}.$$

SI unit: coulomb per second, C/s = ampere, A

The current is the same in any cross section.

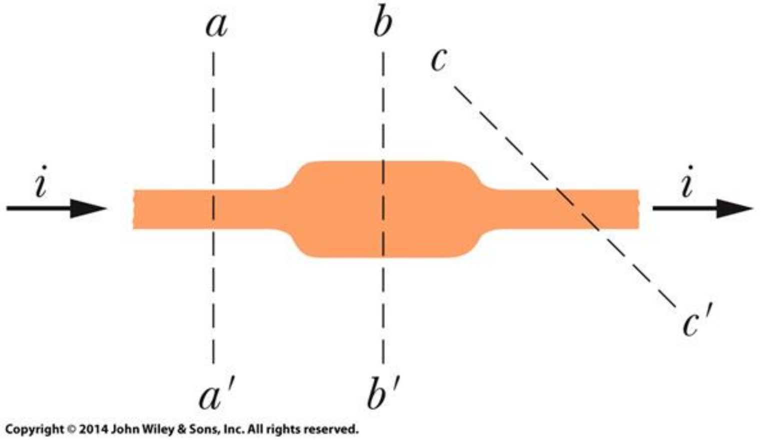
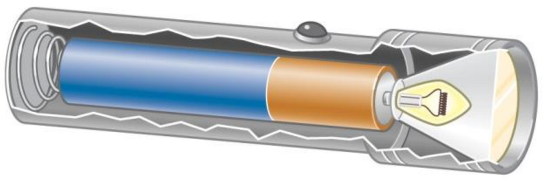


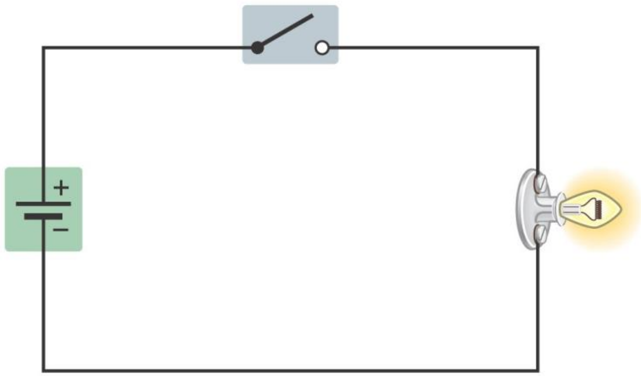
Figure (c)

So , electric current is the flow of electric charge from one place to another in a closed path returning to its starting point.

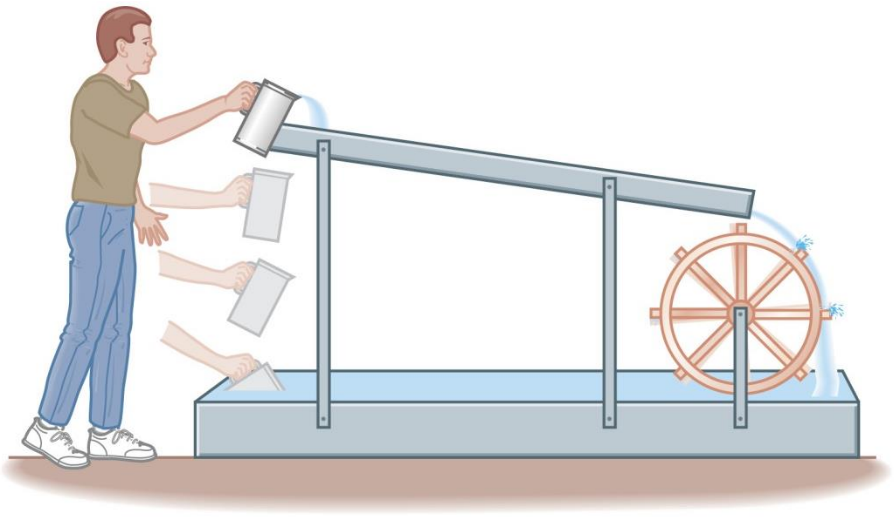
A battery uses chemical reactions to produce a potential difference between its terminals. It causes current to flow through the flashlight bulb similar to the way the person lifting the water causes the water to flow through the paddle wheel.

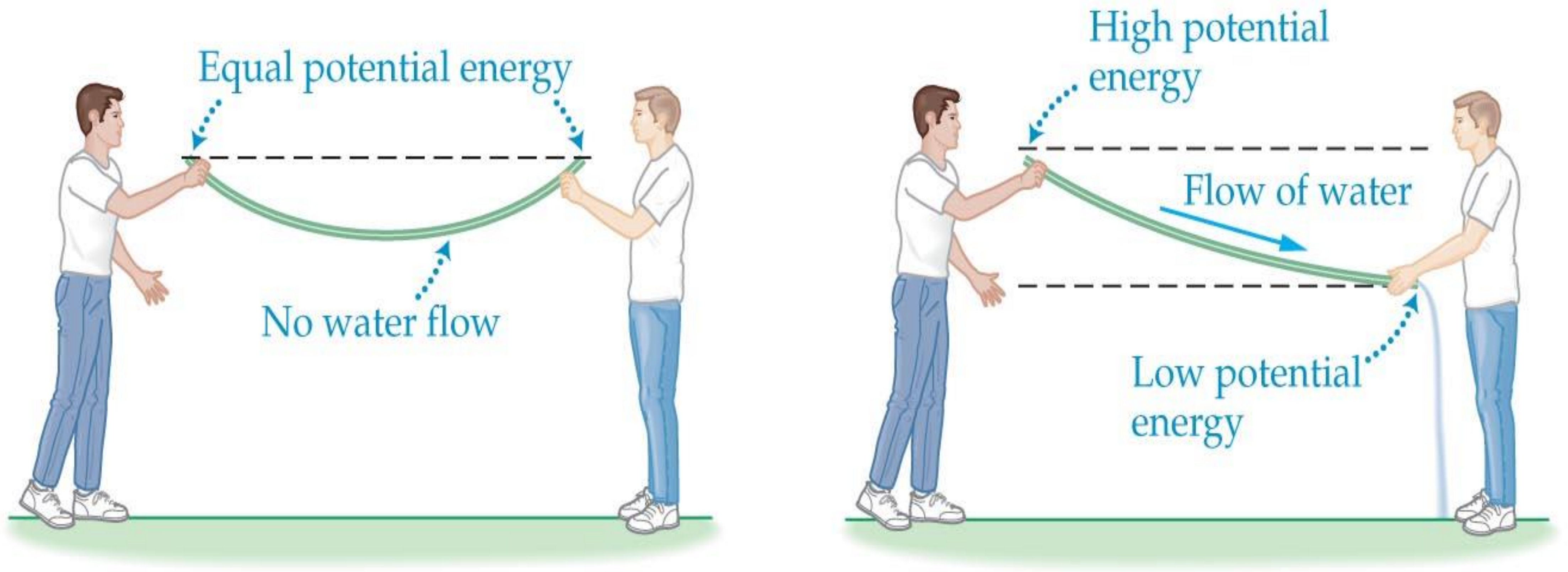


(a)



(b)





(a) Equal potential energy → no flow

(b) Water flows from high potential energy to low

Generator potential difference (V)
same thing
electromotive force
(not force rather energy/charge)

A battery that is disconnected from any circuit has an electric potential difference between its terminals that is called the electromotive force or *emf*:

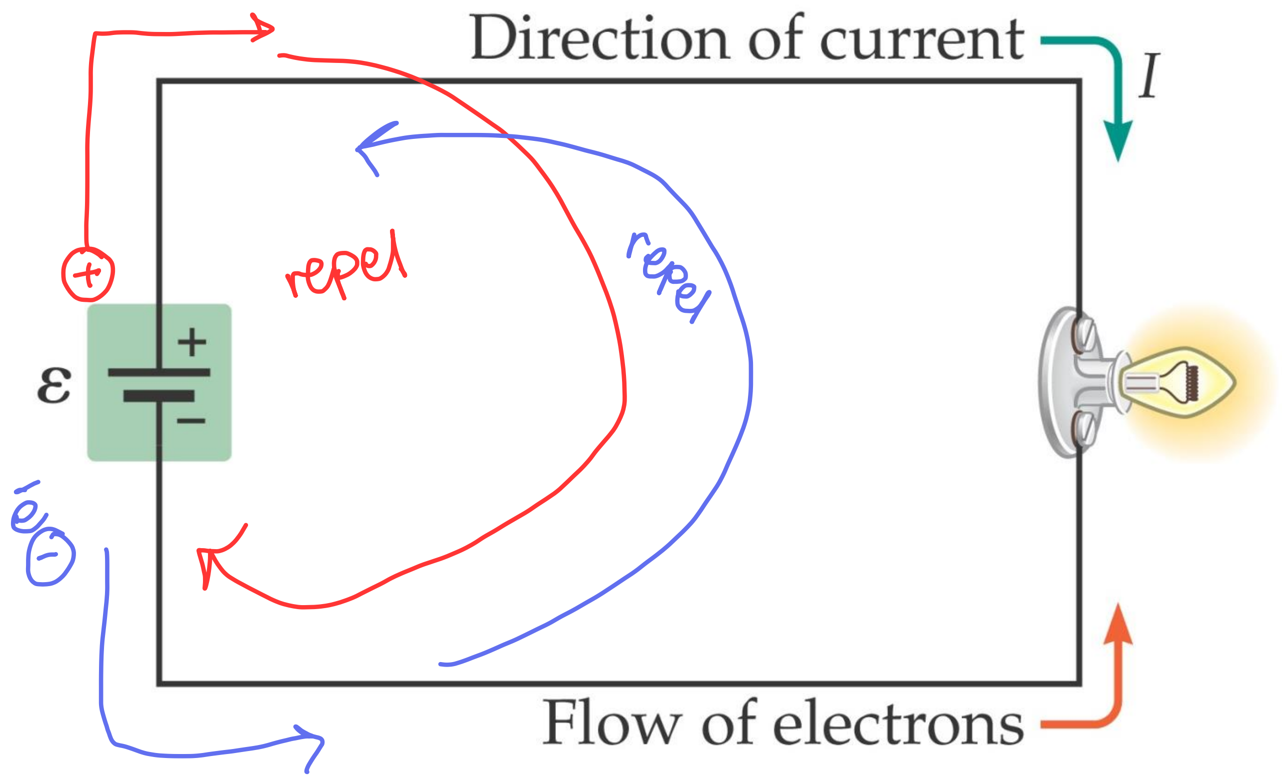
$$emf\ (\mathcal{E})$$

Remember – despite its name, the *emf* is an electric potential, not a force.

The amount of work it takes to move a charge ΔQ from one terminal to the other is:

$$W = \Delta Q\,\mathcal{E}$$

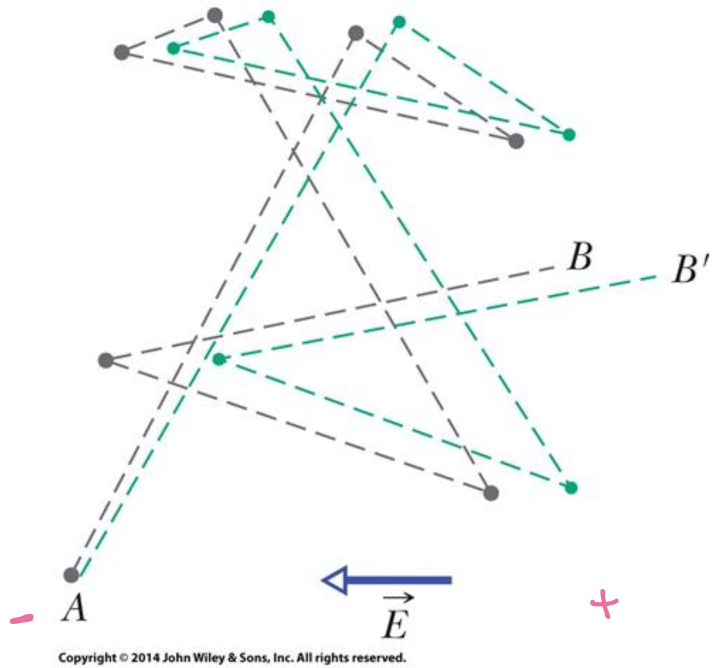
The direction of current flow – from the positive terminal to the negative one – was decided before it was realized that electrons are negatively charged. Therefore, current flows around a circuit in the direction a positive charge would move; electrons move the other way. However, this does not matter in most circuits.



Net Electron Displacement in Electric Field

Drift velocity:
⊖ going opposite to force

electrons don't have it easy want to walk in straight line but can't



The gray lines show an electron moving from *A* to *B*, making six collisions en route. The green lines show what the electron's path might be in the presence of an applied electric field $\vec{E}$. Note the steady drift in the direction of $-\vec{E}$.

$I = \frac{dq}{dt}$ → C, → s

not many exercises on the derivative

$\frac{C}{s} = A$

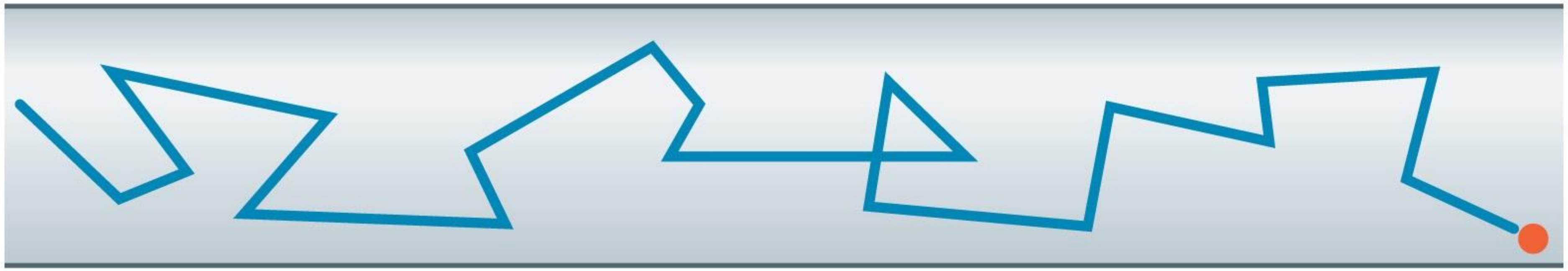
$I = \frac{Q}{t}$

$Q = (N)(1.6 \times 10^{-19}\,C)$

N: number of electrons lost/gained

$1.6 \times 10^{-19}\,C$: charge

In other words, the actual motion of electrons along a wire is quite slow; the electrons spend most of their time bouncing around randomly, and have only a small velocity component opposite to the direction of the current. (The electric *signal* propagates much more quickly!)



Electric Current: Checkpoint #1

A current of 5 mA is passing through a certain wire

a) What charge flows through the cross sectional area of the wire in 10 min?

Current $= 5\times10^{-3}$ A

$T = 10 \text{ min} \times \frac{60 \text{ s}}{1 \text{ min}} = 600 \text{ s}$

$Q = IT = 3\text{ C}$

b) How many electrons flow through the cross sectional area of the wire in 10 min

$Q = (N)(1.6\times10^{-19})$

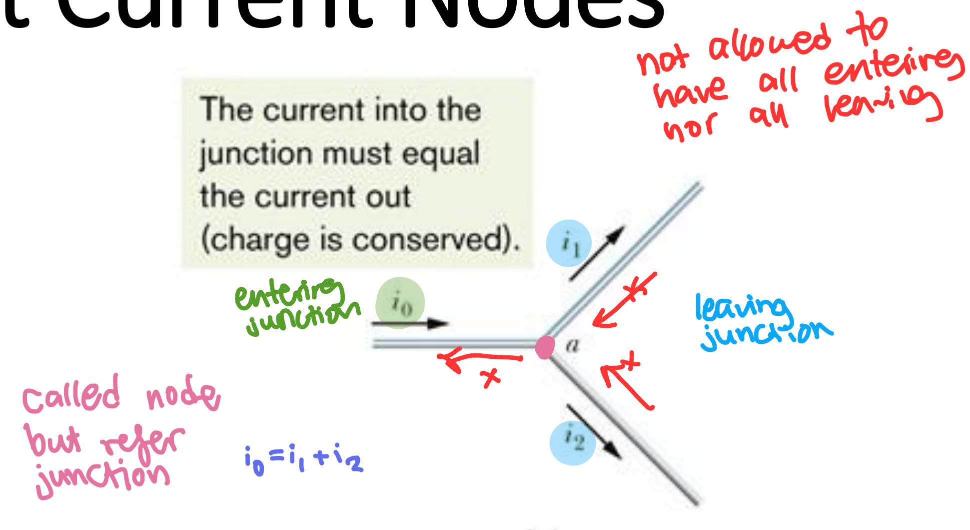
$\frac{3}{1.6\times10^{-19}} = \frac{(N)(1.6\times10^{-19})}{1.6\times10^{-19}}$

$N = 1.875\times10^{19}$ electrons

Conservation of Charge at Current Nodes

Figure (a) shows a conductor with current i_0 splitting at a junction into two branches. Because charge is conserved, the magnitudes of the currents in the branches must add to yield the magnitude of the current in the original conductor, so that

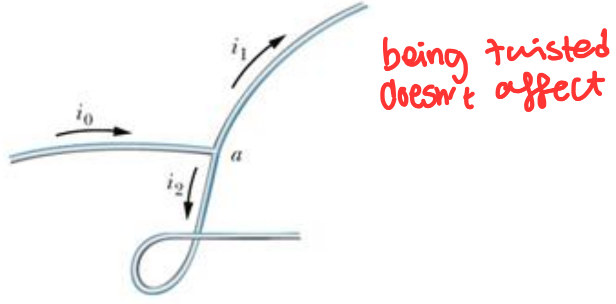
$$i_0 = i_1 + i_2.$$



(a)

Figure (b) suggests, bending or reorienting the wires in space does not change the validity of the above equation

Current arrows are drawn in the direction in which positive charge carriers would move, even if the actual charge carriers are negative and move in the opposite direction.

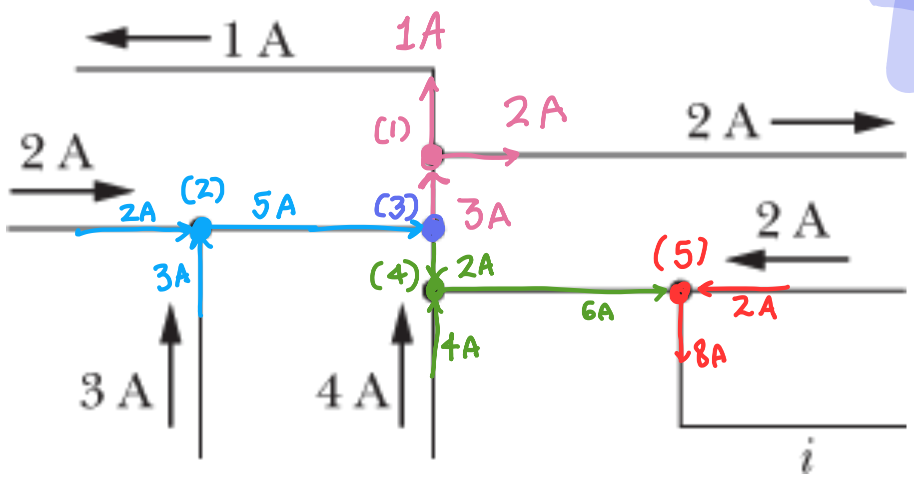


(b)

Electric Current: Checkpoint #2

The figure here shows a portion of a circuit. What are the magnitude and direction of the current *i* in the lower right-hand wire?

fun!!



Answer: 8A with arrow pointing right

Section 26.4 Ohm's Law

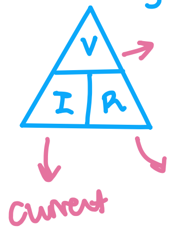
Ohm's Law Definition

Figure below demonstrates Ohm's Law on a conductor. A potential difference *V* is applied across the device being tested, and the resulting current *i* through the device is measured as *V* is varied in both magnitude and polarity.

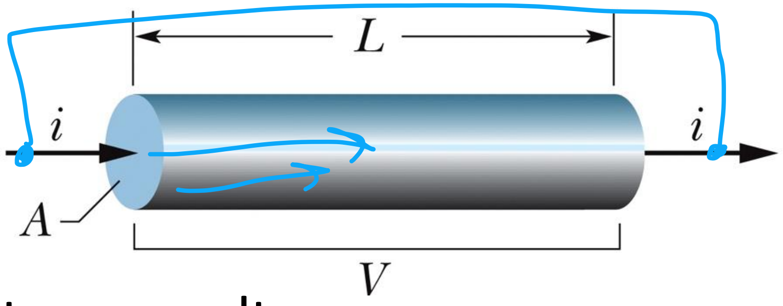
$$V = IR$$

$$I = V/R$$

Mistakes:
In quiz, wrote formula wrong



Current is driven by a potential difference.



The units of resistance, volts per ampere, are called ohms: $1\ \Omega = 1\ \mathrm{V/A}$

Linear Current vs. Voltage Relationship

Figure (b) is a plot of *i* versus *V* for a conductor. This plot is a straight line passing through the origin, so the ratio $\frac{i}{V}$ (which is the slope of the straight line) is the same for all values of *V*. This means that the resistance $R = \frac{V}{i}$ of the device is independent of the magnitude and polarity of the applied potential difference *V*.

$V = IR$

$y = mx$

x: independent

y: dependent

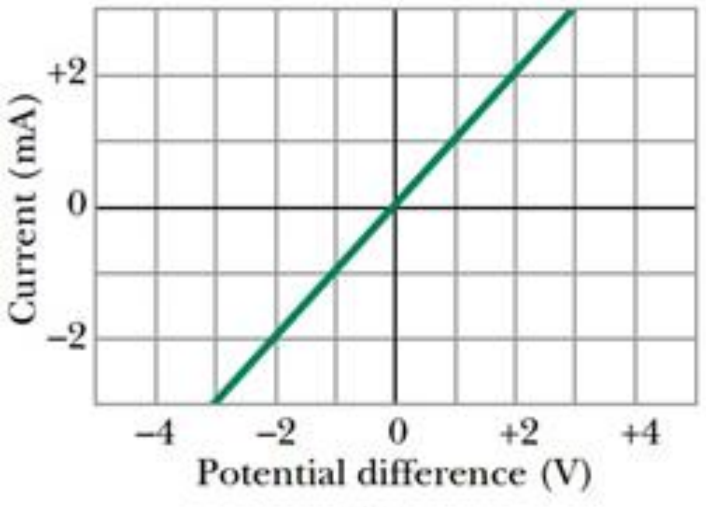
$i = \frac{V}{R}$

slope $= \frac{1}{R}$

obtain same

$i = \frac{1}{R} V$

$y = m x$



(b)

$I = \frac{V}{R}$

$I = \frac{1}{R} \times V$

slope

$y = m \quad x$

Tue 31 Mar

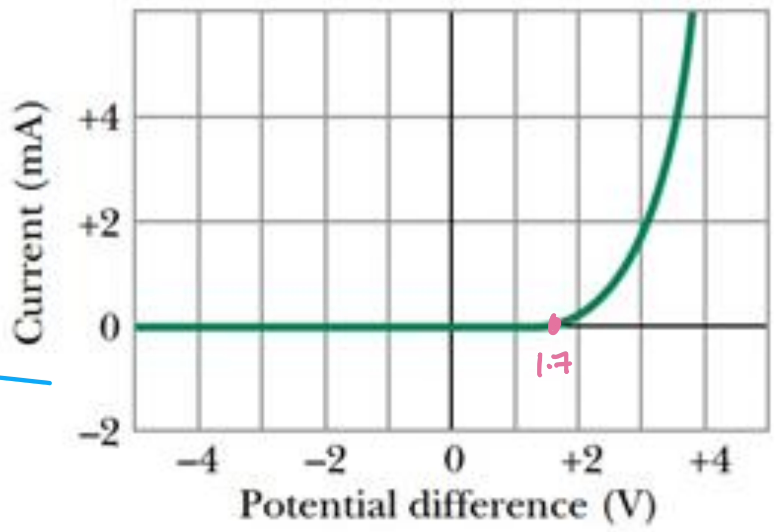
Non-linear Current vs. Voltage Relationship

Figure (c) is a plot for another conducting device. Current can exist in this device only when the polarity of *V* is positive and the applied potential difference is more than about 1.5 *V*. When current does exist, the relation between *i* and *V* is not linear; it depends on the value of the applied potential difference *V*.

Here not linear, rather curved.

As long as 0 < V < 1.7, there's no current

Beyond that, we get a reading for a current



(c)

Ohm's Law: Checkpoint #3

The following table gives the current *i* (in amperes) through two devices for several values of potential difference *V* (in volts). From these data, determine which device does not obey Ohm's law.

Device 1	Device 1	Device 2	Device 2
V	i	V	i
2.00	4.50	2.00	1.50
3.00	6.75	3.00	2.20
4.00	9.00	4.00	2.80

Answer: Device 2 does not follow ohm's law.

Section 26.3 Resistance and Resistivity

Resistance vs. Conductor Dimensions

Resistance is a property of an object. Resistivity is a property of a material.

Two wires of the same length and diameter will have different resistances if they are made of different materials. This property of a material is called the resistivity ***ρ***.

The resistance *R* of a conducting wire of length *L* and uniform cross section A is

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

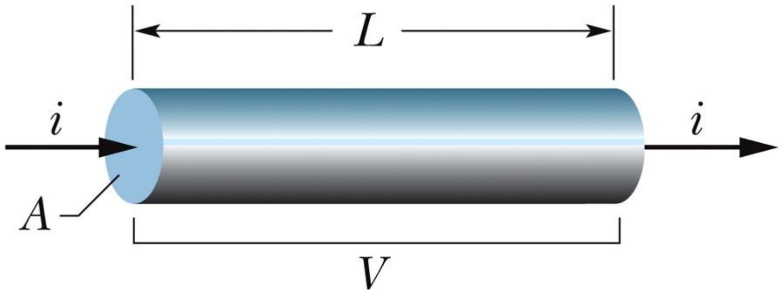
Ω Ωm m m^2

cylinder resistance

if L > so resisting more

if A > flow is easier so less resisting

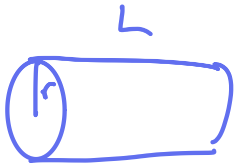
Therefore inversely proportional



$A = \pi r^2$

diameter $= 2r$

$A = \frac{\pi D^2}{4}$



Resistivity values given no need

The difference between insulators, semiconductors, and conductors can be clearly seen in their resistivities:

memorize

TABLE 21–1 Resistivities

Substance	Resistivity, $\rho\ (\Omega \cdot m)$
Insulators	
Quartz (fused)	7.5×10^{17}
Rubber	1 to 100×10^{13}
Glass	1 to $10{,}000 \times 10^{9}$
Semiconductors	
Silicon*	0.10 to 60
Germanium*	0.001 to 0.5
Conductors	
Lead	22×10^{-8}
Iron	9.71×10^{-8}
Tungsten	5.6×10^{-8}
Aluminum	2.65×10^{-8}
Gold	2.20×10^{-8}
Copper	1.68×10^{-8}
Silver	1.59×10^{-8}

*The resistivity of a semiconductor varies greatly with the type and amount of impurities it contains. This property makes them particularly useful in electronic applications.

Big numb resisting

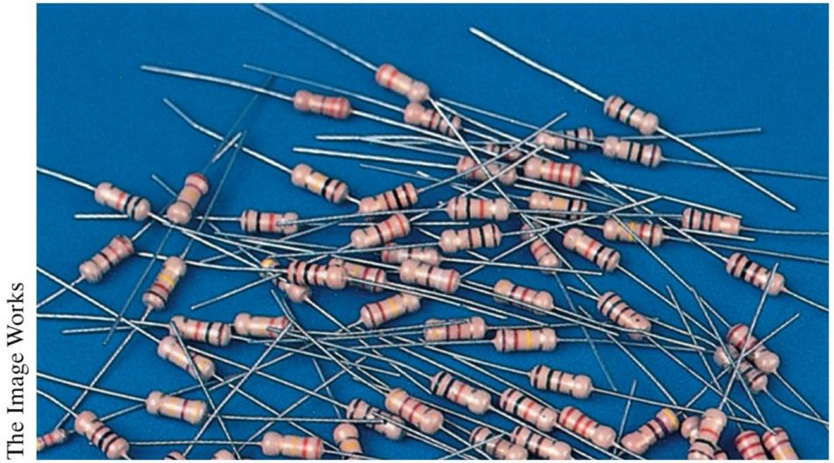
main ones we deal w/

Resistivity vs. Conductivity

inversely proportional

The reciprocal of resistivity is **conductivity** σ of the material:

$$\sigma = \frac{1}{\rho} \quad (\text{definition of } \sigma).$$



Assortment of Resistors

Ohm's law

Checkpoint # 4

1. A car has a 12 V system. The headlights are on a 10 A circuit. How much resistance do they have?

$V = IR =$ $R = \frac{V}{I} = \frac{12}{10} = 1.2\,\Omega$

$V = 12V$

$I = 10A$

2. Your house uses 120 volts. What amount of current would flow through a 20 Ω resistor?

$V = 120\ V$

$R = 20\ \Omega$

$I = ?$

$I = \frac{V}{R} = \frac{120}{20} = 6A$

3. A 6 Ω resistor has a power source of 20V across it. What will happen to the resistance if the voltage doubles?

$R = 6\,\Omega$

$V = 20V$ → so 40V

$R = \frac{V}{I}$

Resistance not affected by current. So stay same regardless by current/voltage

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

$A = \pi r^2 = \frac{\pi D^2}{4}$

!! Checkpoint # 5 IMP !!

Wire 1 has a length L and a circular cross sectional of diameter D. Wire 2 is constructed from the same material as wire 1 and has the same shape, but it's length is 2L and it's diameter is 2D. ↳ same resistivity

Is the resistance of wire 2:

a) The same as that of wire 1 ($R_2 = R_1$)

b) Twice that of wire 1 ($R_2 = 2 R_1$)

c) Half that of wire 1 ($R_2 = R_1/2$)

$R_1 = \frac{\rho L_1}{A_1}$

$R_2 = \frac{\rho 2 L_1}{4 A_1}$

$R_2 = \frac{1}{2} \frac{\rho L_1}{A_1}$

$R_2 = \frac{1}{2} R_1$

$A = \pi r^2$

$A = \frac{\pi D^2}{4}$

$D_2 = 2 D_1$

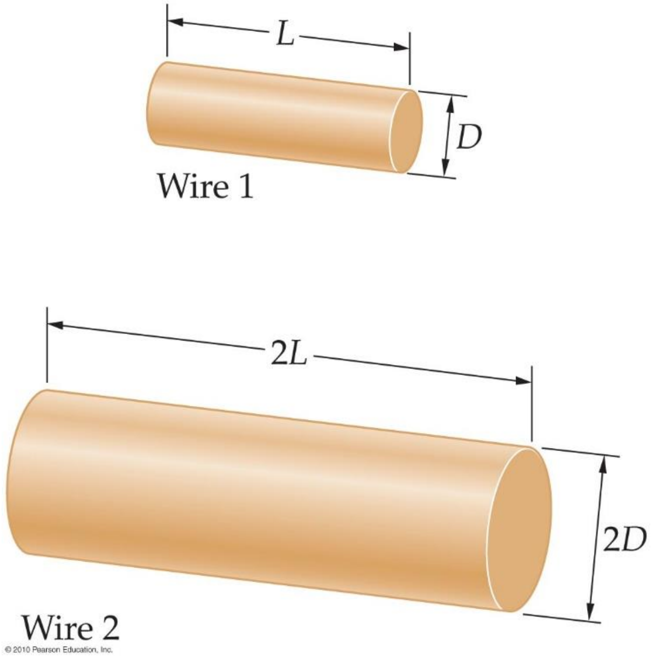
$r_2 = 2 r_1$

$A_2 = \pi (2 r_1)^2$

$= \pi 4 r_1^2$

$A_2 = 4 \underbrace{\pi r_1^2}_{A_1}$

$A_2 = 4 A_1$



Checkpoint # 6

1. A conducting wire is quadrupled in length and tripled in diameter.

a) does its resistance increase, decrease, or stay the same?

4L 3D

$R = \frac{\rho L}{A} = \frac{\rho(4L)}{9A}$

b) by what factor does its resistance change?

$\frac{4}{9} < 1$ so decrease

2. A current of (1.82 A) flows through a copper wire (1.75 m) long and (1.1 mm) in diameter. Find the potential difference between the ends of the wire. (**ρ** for copper = 1.68 x 10^{-8} **Ω**.m)

$A = \frac{\pi (1.1\times10^{-3})^2}{4}$

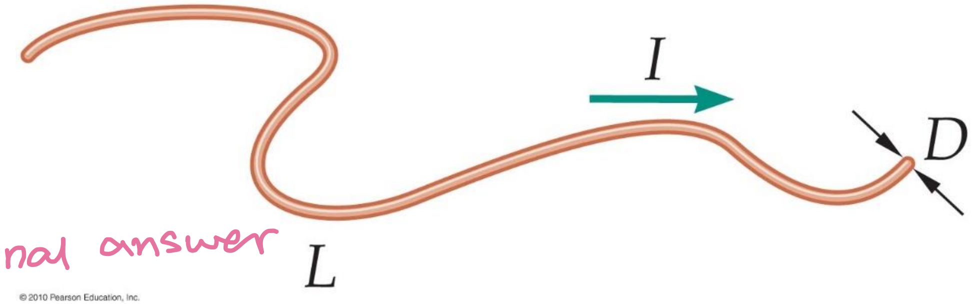
$I = 1.82\,A$

$L = 1.75\,m$

$D = 1.1\,mm \rightarrow 1.1\times10^{-3}\,m$

$\rho = 1.68\times10^{-8}\,\Omega m$

$R = \frac{\rho L}{A} \rightarrow (1.68\times10^{-8})\frac{(1.75)}{\frac{\pi D^2}{4}} = 0.03\,\Omega$



Final answer

$V = IR$

$= 0.0546\,V$

Checkpoint # 7

opposite of resist

The figure here shows three cylindrical copper conductors along with their face areas and lengths. Rank them according to the current through them, greatest first, when the same potential difference V is placed across their lengths. → same resistance

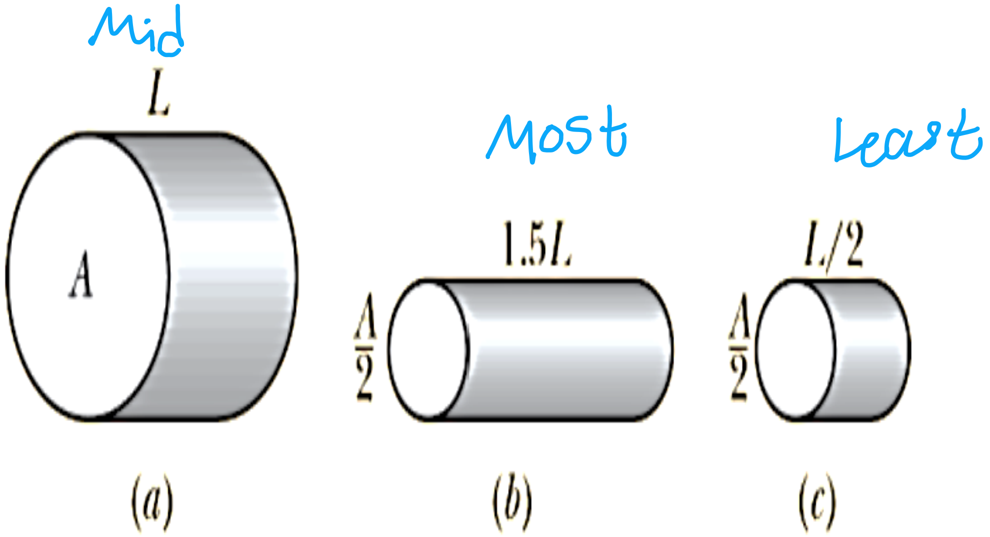
L short
D=?
R=0.10Ω

V & R same

$R_1 = \frac{\rho L}{A}$

$R_2 = \frac{\rho 1.5L}{\frac{A}{2}} = \frac{3\rho L}{A}$

$R_3 = \rho \frac{\frac{L}{2}}{\frac{A}{2}} = \frac{\rho L}{A} = R_1$



$R_1 = R_3 < R_2$

Same current but calc diff potential

$V = IR$

I↑ R↓ because V constant

$I_1 = I_3 > I_2$

if I constant Relation between V & R is proportional so then it would be $V_1 = V_3 < V_2$

Wed 1 Apr

Checkpoint # 8

L=20m
D=?
R=0.10Ω

Suppose you want to connect your stereo to remote speakers.

(a) If each wire must be 20 m long, what diameter copper wire should you use to make the resistance 0.10 Ω per wire.

(b) If the current to each speaker is 4.0 A, what is the voltage drop across each wire?

(a) $R = \frac{\rho L}{\frac{\pi (D^2)}{4}} \rightarrow 0.10 = \frac{\rho (20)}{\frac{\pi (D^2)}{4}} \rightarrow 0.10 = \frac{\frac{1.68\times10^{-8}(20)}{1}}{\frac{\pi D^2}{4}} \rightarrow 0.10 = \frac{(1.68\times10^{-8})(20)(4)}{\pi D^2}$

$\pi D^2 = \frac{(1.68\times10^{-8})(20)(4)}{0.10}$

$\frac{\pi D^2}{\pi} = \frac{0.00001344}{\pi}$

$\sqrt{D^2} = \sqrt{0.00000427808}$

$D = 0.002 m$

(b) $V = IR = 0.10 \times 4 = 0.4V$

Resistivity vs. Temperature

The resistivity ρ for most materials changes with temperature.

For many materials, including metals, the relation between ρ and temperature T is approximated by the equation

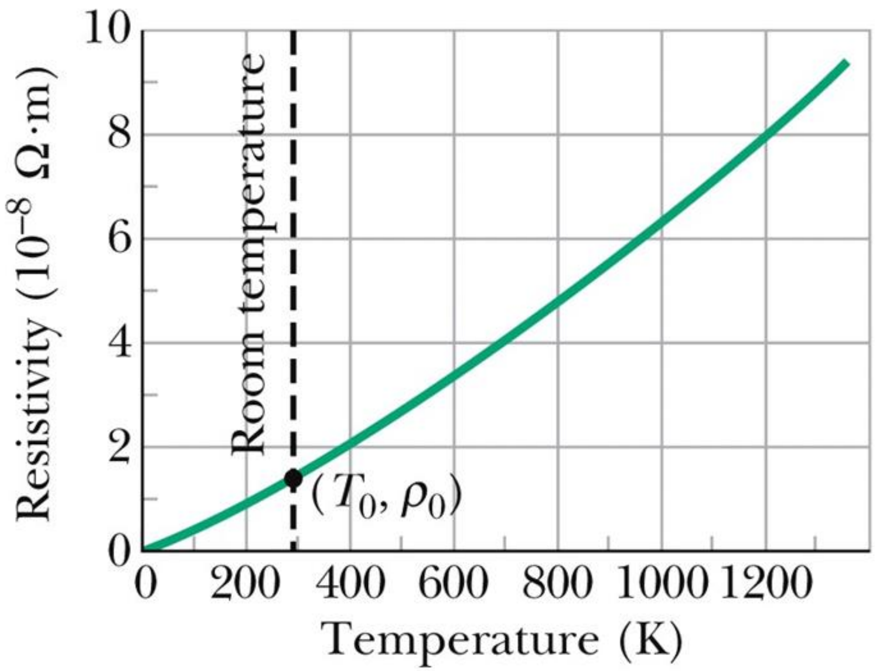
$$\rho - \rho_0 = \rho_0 \alpha \left(T - T_0\right).$$

Here T_0 is a reference temperature ρ_0 is the resistivity at T_0, and α is the temperature coefficient of resistivity for the material.

$$R - R_0 = R_0 \alpha (T - T_0)$$

Temperature Dependence of Resistivity for a Metallic Conductor

The resistivity of copper as a function of temperature.



OK no resistivity

Resistivity vs. Temperature

No need to memorize, given

Material	Resistivity, ρ $(\Omega \cdot \text{m})$	Temperature Coefficient of Resistivity, α (K^{-1})
Typical Metals		
Silver	1.62×10^{-8}	4.1×10^{-3}
Copper	1.69×10^{-8}	4.3×10^{-3}
Gold	2.35×10^{-8}	4.0×10^{-3}
Aluminum	2.75×10^{-8}	4.4×10^{-3}
Manganina[a]	4.82×10^{-8}	0.002×10^{-3}
Tungsten	5.25×10^{-8}	4.5×10^{-3}
Iron	9.68×10^{-8}	6.5×10^{-3}
Platinum	10.6×10^{-8}	3.9×10^{-3}
Typical Semiconductors		
Silicon, pure	2.5×10^{3}	-70×10^{-3}
Silicon, *n*-type[b]	8.7×10^{-4}	
Silicon, *p*-typec[c]	2.8×10^{-3}	
Typical Insulators		
Glass	$10^{10}–10^{14}$	
Fused quartz	$\sim 10^{16}$	

α

Checkpoint # 9

At what temperature would the resistance of a copper conductor be double its resistance at 20.0°C?

$T = ?$ $T_0 = 20°C$

$2R_0$

$\alpha = 4.3 \times 10^{-3}$ K

$R = R_0(1 + \alpha(T - T_0))$

$2R_0 = R_0(1 + \alpha(T - T_0))$

$P =$

Section 26.5 Power, Semiconductors, and Superconductors

Power Dissipation in an Electric Circuit

Figure (next slide) shows a circuit consisting of a battery B that is connected by wires (negligible resistance), to an unspecified conducting device. The device might be a resistor, a storage battery (a rechargeable battery), a motor, or some other electrical device. The battery maintains a potential difference of magnitude V across its own terminals and thus (because of the wires) across the terminals of the unspecified device, with a greater potential at terminal a of the device than at terminal b.

The power P, or rate of energy transfer, in an electrical device across which a potential difference V is maintained is

$$P = iV \quad (\text{rate of electrical energy transfer}).$$

Thu 2 Apr

watts (W)

$V = iR$

Power = work/energy / time (s)

Joules (J)

$P = iV$

$P = i^2R$

$P = \frac{V^2}{R}$

constant V? use these

how to choose? look at which thing is constant

kwatt·h → work/Energy

Watts = J/s | Joules = Watts·s | 1Kwh = 1000W × 3600s = 3.6×10^6 Ws = 1KWh = 3.6×10^6 J

Power in terms of Current and Resistance

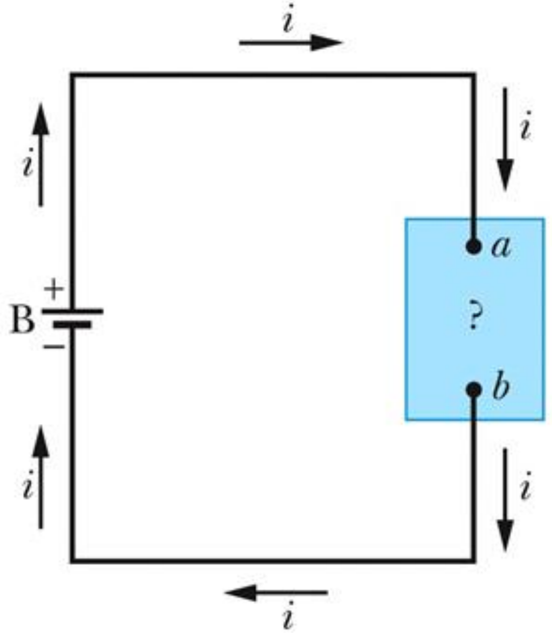
If the device is a resistor, the power can also be written as:

$$P = i^2 R \quad \text{(resistive dissipation)}$$

or,

$$P = \frac{V^2}{R} \quad \text{(resistive dissipation).}$$

The battery at the left supplies energy to the conduction electrons that form the current.



Energy and Power in Electric Circuits

When the electric company sends you a bill, your usage is quoted in kilowatt-hours (kWh). They are charging you for energy use, and kWh are a measure of energy.

$$\begin{aligned} 1 \text{ kilowatt-hour} &= (1000 \text{ W})(3600 \text{ s}) = (1000 \text{ J/s})(3600 \text{ s}) \\ &= 3.6 \times 10^6 \text{ J} \end{aligned}$$

Checkpoint # 9

1. An electric heater is constructed by applying a potential difference of 110 volt across a wire with resistance 5 Ω.

a) What is the power rating of the heater?

$V = 110V$
$R = 5\Omega$ → $P = \frac{V^2}{R} = \frac{(110)^2}{5} = 2420\ W$
$P = ?$

t seconds → SI unit
↓
E Joules

b) What is the electric energy dissipated in the heater in 3 min?

$t = 3\ min \rightarrow 3 \times 60 = 180s$
$E = P \cdot t = 2420 \cdot (180) = 435600\ J$

2. A light bulb is rated at 30 watt when operated at 120 volt.

a) How much charge passes through this bulb in 2 minutes ?

$P = 30\ W$
$V = 120V$
$i = \frac{Q}{t}$ (A, C, s)

$P = iV \rightarrow i = \frac{P}{V}$
$t \times i = Q$
$t \times \frac{P}{V} = Q$ → $(120)\frac{30}{120} = Q = 30$

b) What is the electric energy dissipated in this bulb in half an hour?

$E = P \cdot t = 30 \cdot$
$540000J$

Checkpoint #10

A battery that produces a potential difference V is connected to a 5 W light bulb. Later, the 5 W light bulb is replaced with a 10 W light bulb.

$P = iV$ → constant

$P\uparrow$ $i\uparrow$

$10W > 5W$

$i_{10W} > i_{5W}$

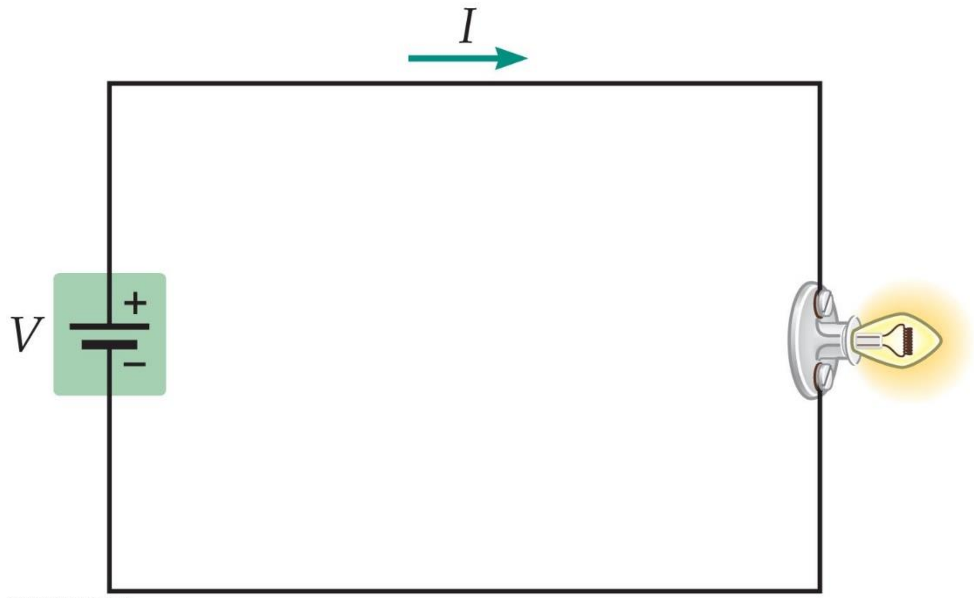
a) In which case does the battery supply more current? 10 because

b) Which light bulb has the greater resistance? 5 because $P = \frac{V^2}{R}$ → constant

$P\uparrow$ $R\downarrow$

$P_{10W} > P_{5W}$

$R_{10W} < R_{5W}$



Checkpoint #11

The current in a 120 V reading lamp is 2.6 A. If the cost of electrical energy is 0.075 $ per kilowatt-hr, how much does it cost to operate the light for an hour? in exam given 15 min instead

Solution:

Power = IV = (120)(2.6)= 312 W

Energy consumed = P Δ t = (0.312 kW).(1 hr) = 0.312 kW.h

Cost = 0.312 x 0.075 = 0.023 $

V=120V
i=2.6A
0.075$ 1KWh

P=iV=120×2.6=312W ⇒ 0.312KW

E=P·t =0.312 KW ×1h = 0.312KWh

1KWh → 0.075
0.312KWh → ?

$\frac{0.312 \times 0.075}{1}$ = $ 0.0234

Checkpoint #12

A potential difference V is connected across a device with resistance R, causing current i through the device. Rank the following variations according to the change in the rate at which electrical energy is converted to thermal energy due to the resistance, greatest change first:

a) V is doubled with R unchanged, P quadrupled
b) I is doubled with R unchanged, P quadrupled
c) R is doubled with V unchanged, P halfed
d) R is doubled with i unchanged. P doubled

$P = \frac{(2V)^2}{R} \rightarrow 4V^2 = 4P$

$P = (2i)^2 R \rightarrow 4i^2 R = 4P$

$P = \frac{V^2}{2R} = \frac{P}{2}$

$P = i^2(2R) = 2P$

$P = \frac{E}{t}$

P is rate of energy (means same)

$P_a = P_b > P_d > P_c$

Home Practice

Sample Problem 26.5.1

Rate of energy dissipation in a wire carrying current

You are given a length of uniform heating wire made of a nickel–chromium–iron alloy called Nichrome; it has a resistance R of 72 Ω. At what rate is energy dissipated in each of the following situations? (1) A potential difference of 120 V is applied across the full length of the wire. (2) The wire is cut in half, and a potential difference of 120 V is applied across the length of each half.

KEY IDEA

Current in a resistive material produces a transfer of mechanical energy to thermal energy; the rate of transfer (dissipation) is given by Eqs. 26.5.2 to 26.5.4.

Calculations: Because we know the potential V and resistance R, we use Eq. 26.5.4, which yields, for situation 1,

$$P = \frac{V^2}{R} = \frac{(120\ \text{V})^2}{72\ \Omega} = 200\ \text{W}. \qquad \text{(Answer)}$$

In situation 2, the resistance of each half of the wire is $(72\ \Omega)/2$, or $36\ \Omega$. Thus, the dissipation rate for each half is

$$P' = \frac{(120\ \text{V})^2}{36\ \Omega} = 400\ \text{W},$$

and that for the two halves is

$$P = 2P' = 800\ \text{W}. \qquad \text{(Answer)}$$

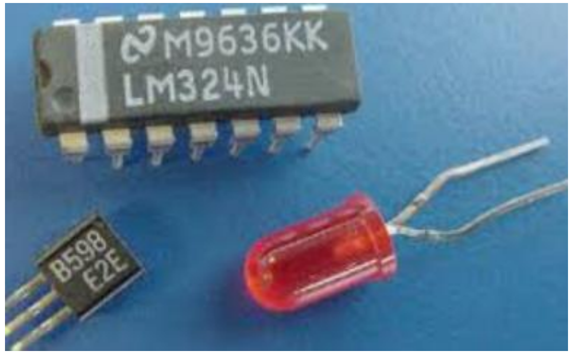
This is four times the dissipation rate of the full length of wire. Thus, you might conclude that you could buy a heating coil, cut it in half, and reconnect it to obtain four times the heat output. Why is this unwise? (What would happen to the amount of current in the coil?)

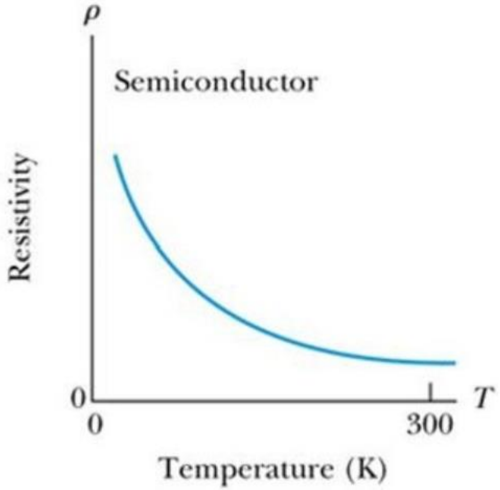
WileyPLUS Additional examples, video, and practice available at *WileyPLUS*

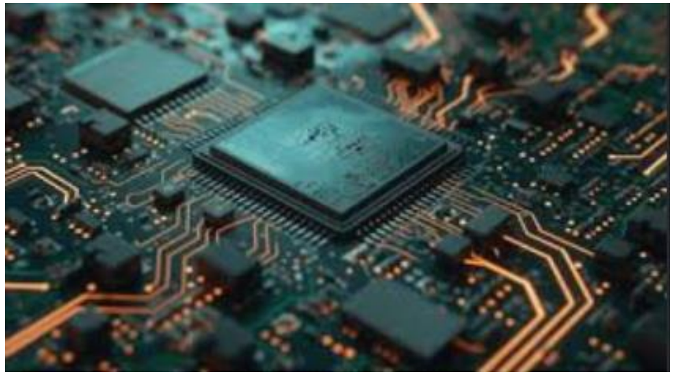
Semiconductor Material Characteristics

Semiconductors are materials that have few conduction electrons but can become conductors when they are doped with other atoms that contribute charge carriers.

In a semiconductor, *n* (number of free electrons) is small (unlike conductor) but increases very rapidly with temperature as the increased thermal agitation makes more charge carriers available. This causes a decrease of resistivity with increasing temperature.

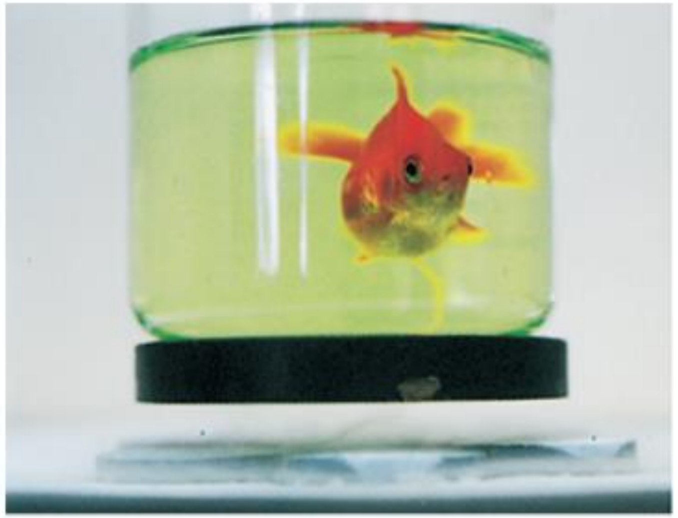






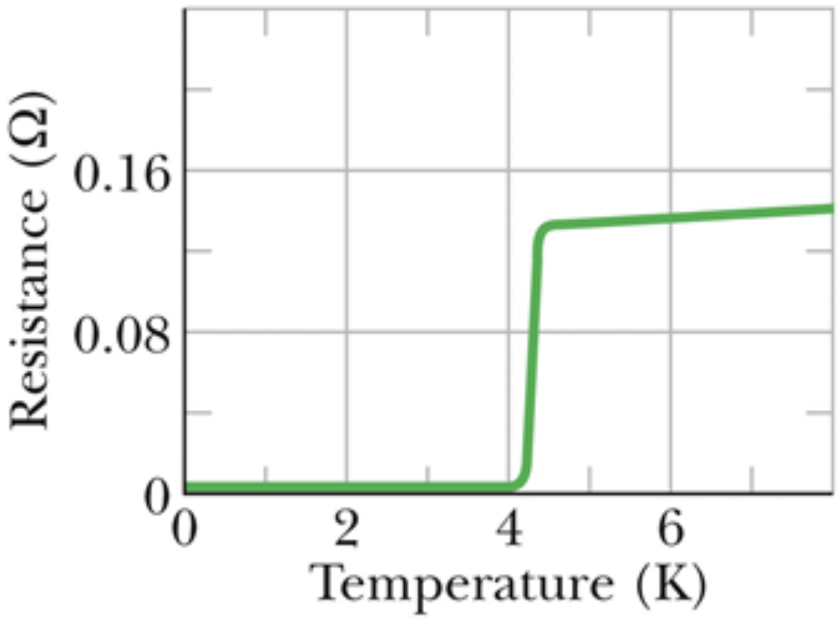
Superconductors

In 1911, Dutch physicist Kamerlingh Onnes discovered that the resistivity of mercury absolutely disappears at temperatures below about 4 K called the critical temperature T_C. This phenomenon of superconductivity is of vast potential importance in technology because it means that charge can flow through a superconducting conductor without losing its energy to thermal energy. Currents created in a superconducting ring, for example, have persisted for several years without loss; the electrons making up the current require a force and a source of energy at start-up time but not thereafter.



Courtesy of Shoji Tonaka/International Superconductivity Technology Center, Tokyo, Japan

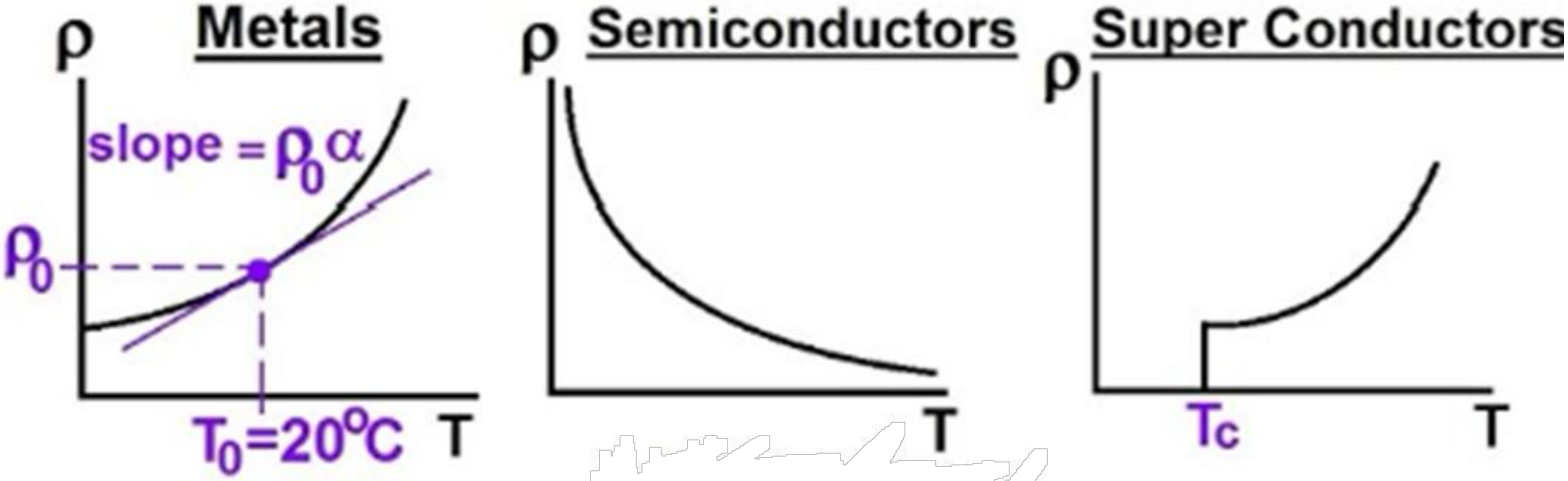
A disk-shaped magnet is levitated above a superconducting material that has been cooled by liquid nitrogen. The goldfish is along for the ride.



The resistance of mercury drops to zero at a temperature of about 4 K.

Resistivity and Room Temperature

Material fall into 3 categories:



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

$\rho = 0$ for $T < T_c$