PHYSICS 1442-003
Fall 2011

Lecture 6
Current and Resistance

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:

$$I \propto V.$$

The ratio of voltage to current is called the resistance:

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

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

$$V = IR.$$

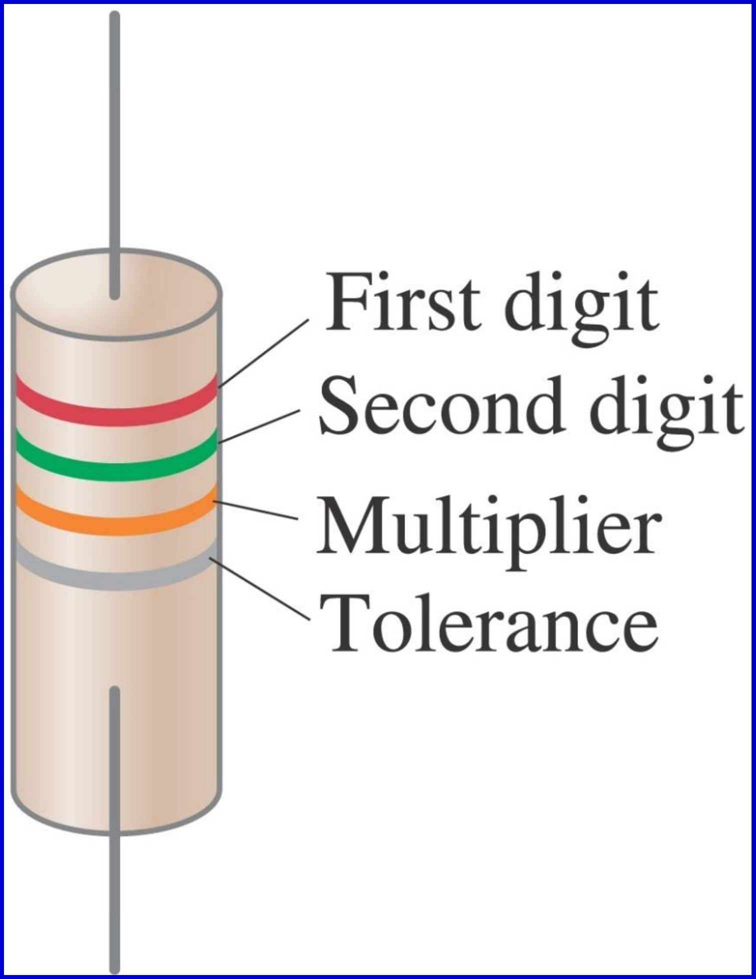
Resistance

- Units of resistance are *ohms* (Ω)
  - 1 Ω = 1 V / A

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

Resistance and Resistors

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



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%

Ohm's Law

- Experiments show that for many materials, including most metals, the resistance remains constant over a wide range of applied voltages or currents
- This statement has become known as *Ohm's Law*
  - $\Delta V = I R$ (or $V = I R$)
- Ohm's Law is an empirical relationship that is valid only for certain materials
  - Materials that obey Ohm's Law are said to be *ohmic*

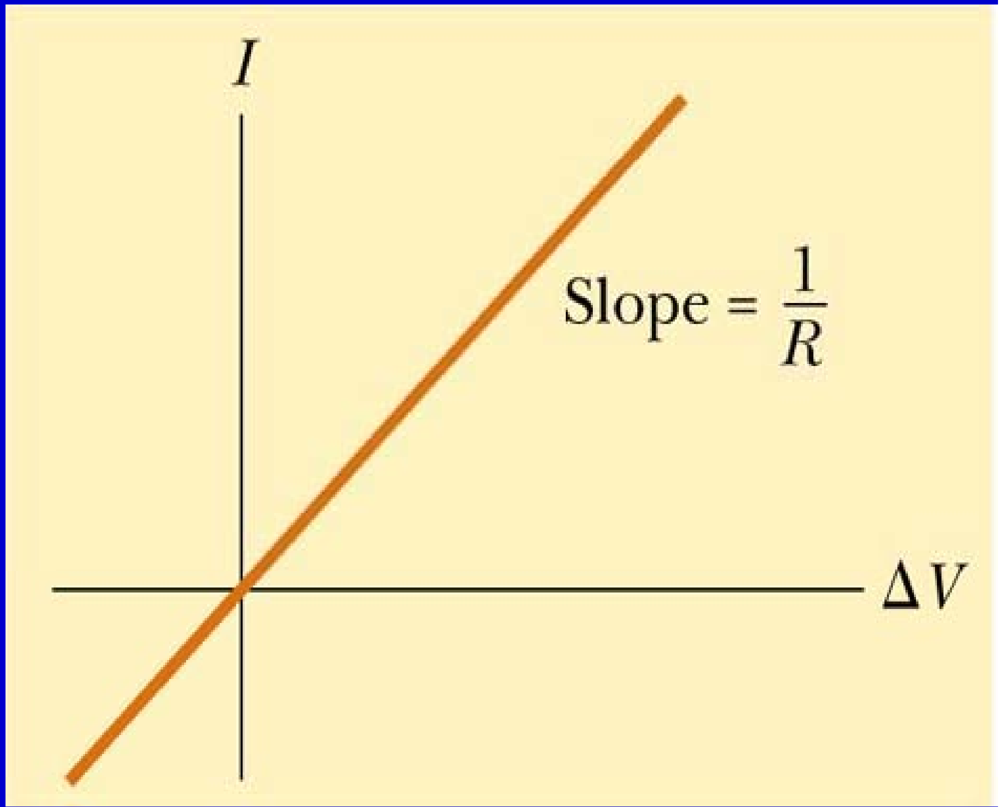
Ohm's Law

In an ohmic device

- The resistance is constant over a wide range of voltages
- The relationship between current and voltage is linear

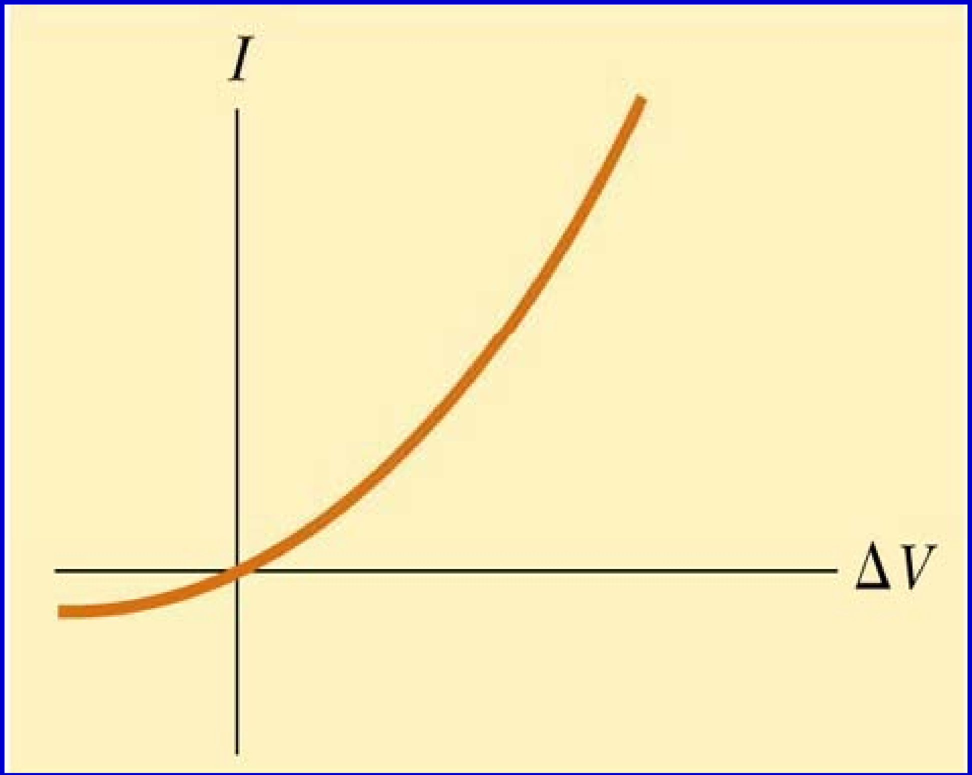
$$I = \Delta V / R$$

- The slope is related to the resistance



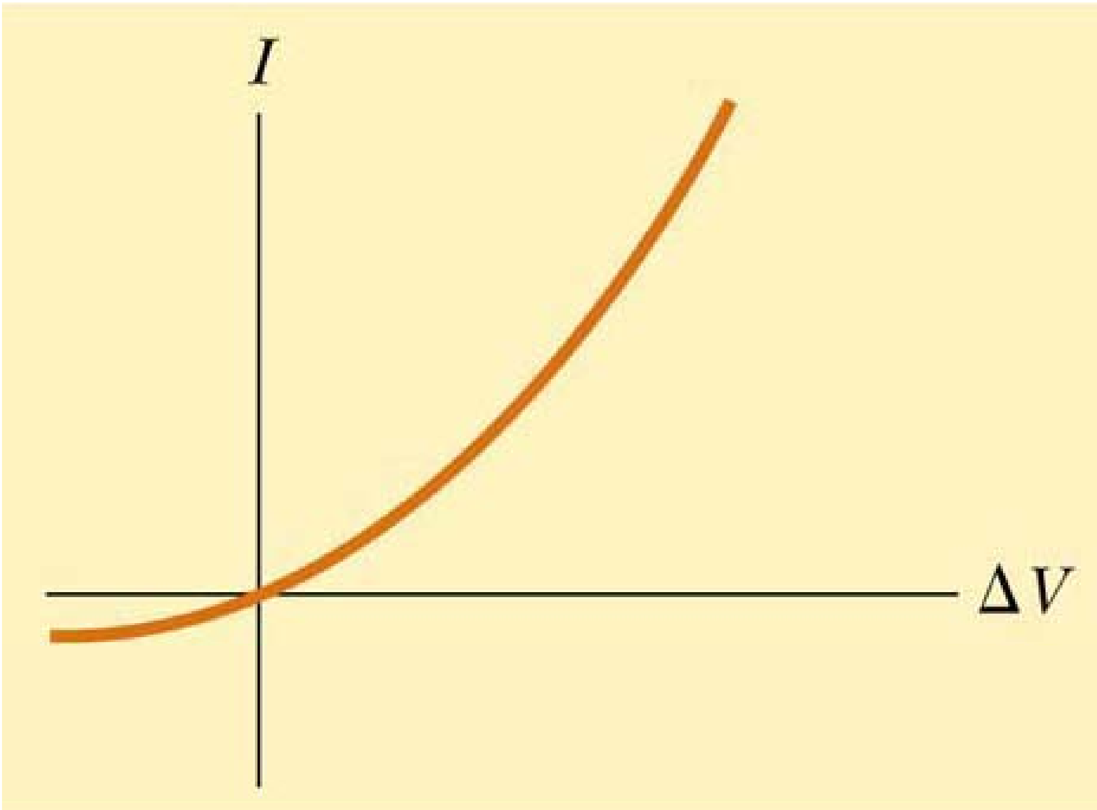
Ohm’s Law

- Non-ohmic materials are those whose resistance changes with voltage or current
- The current-voltage relationship is nonlinear
- A diode is a common example of a non-ohmic device



QUICK QUIZ 3

In the figure below, does the resistance of the diode (a) increase or (b) decrease as the positive voltage ΔV increases?



QUICK QUIZ 3 ANSWER

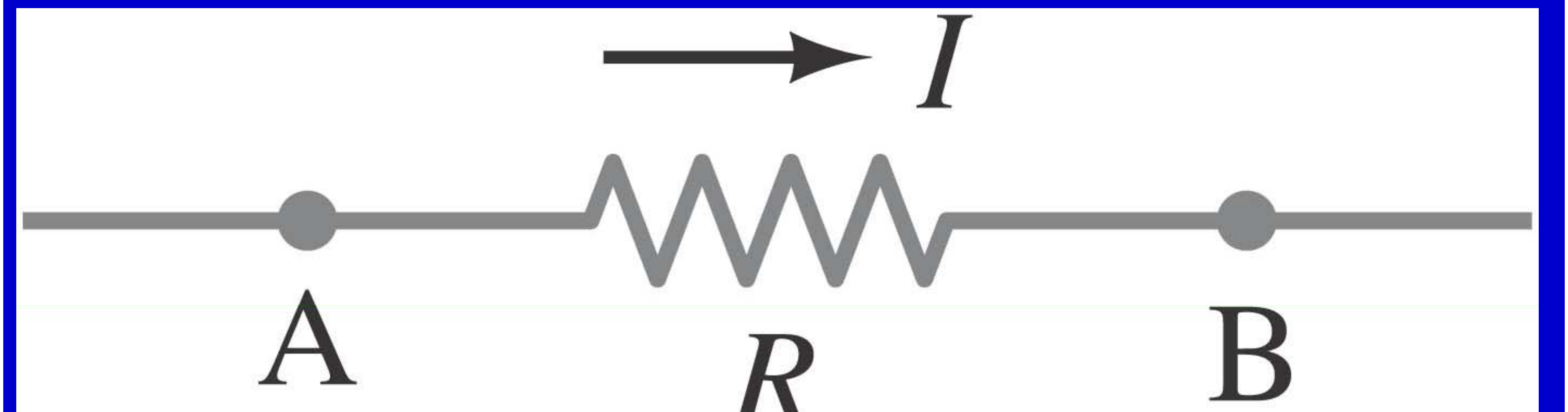
(b). The slope of the line tangent to the curve at a point is the reciprocal of the resistance at that point. Note that as ΔV increases, the slope (and hence $1/R$) increases. Thus, the resistance decreases.

Current and Potential

Current I enters a resistor R as shown.

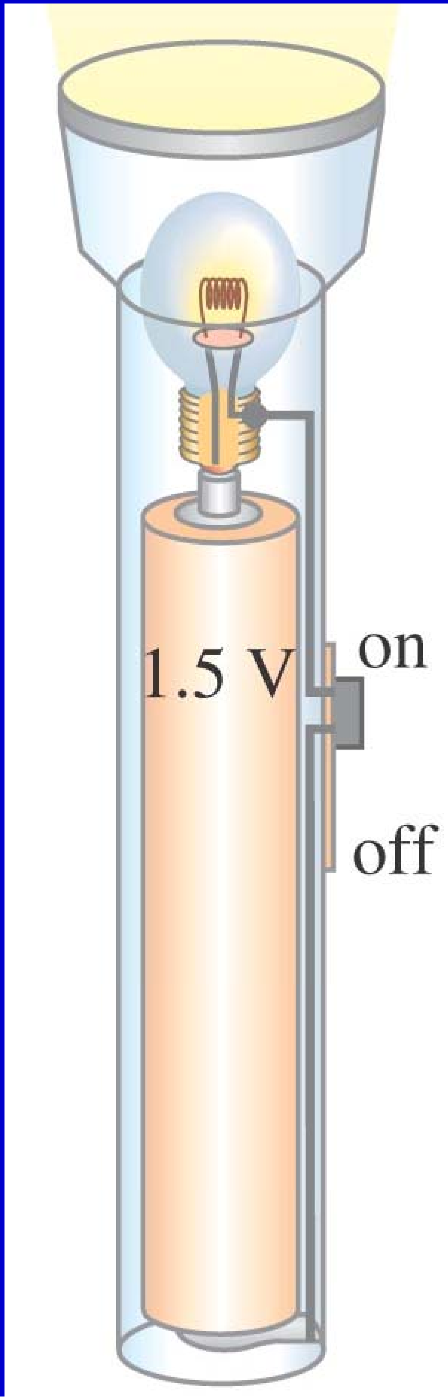
(a) Is the potential higher at point A or at point B?

(b) Is the current greater at point A or at point B?



Flashlight bulb resistance

A small flashlight bulb draws 300 mA from its 1.5-V battery.
(a) What is the resistance of the bulb?
(b) If the battery becomes weak and the voltage drops to 1.2 V, how would the current change?



Resistivity

- The resistance of an ohmic conductor is proportional to its length, L, and inversely proportional to its cross-sectional area, A

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

  - ρ is the constant of proportionality and is called the *resistivity* of the material

Resistivity

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

Material	Resistivity, ρ ($\Omega \cdot m$)	Temperature Coefficient, α $(C°)^{-1}$
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	$10^{13} – 10^{15}$	

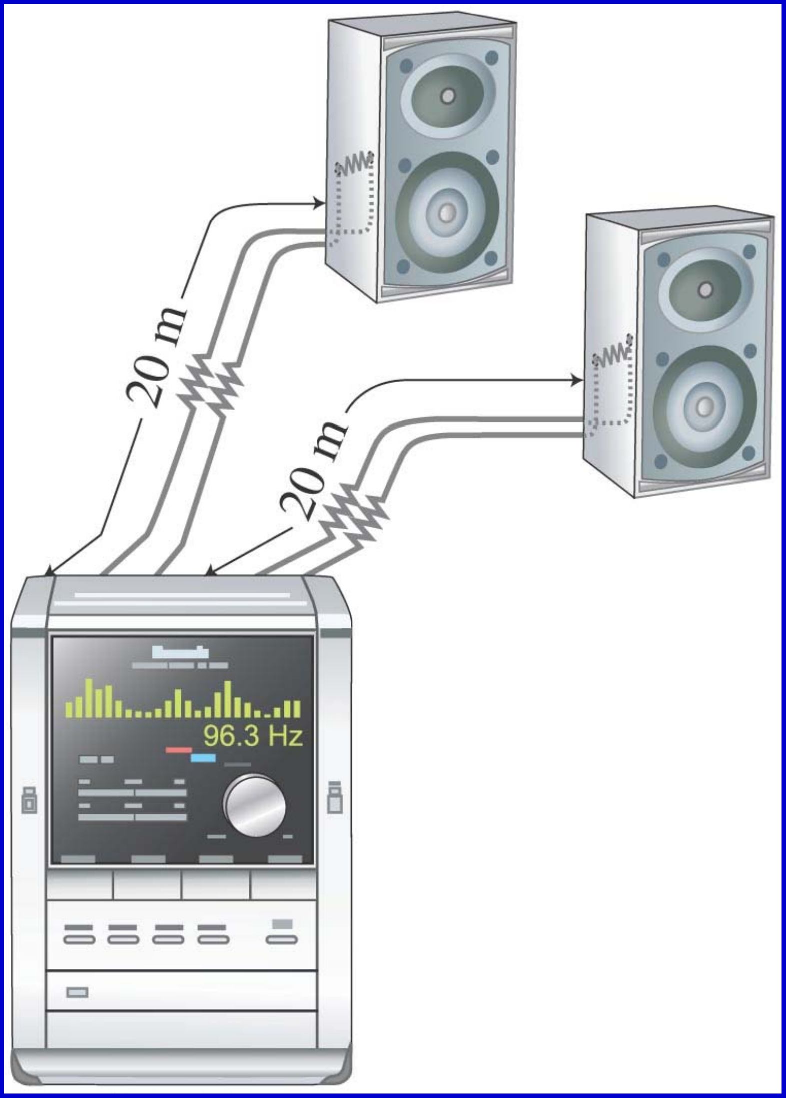
† Values depend strongly on the presence of even slight amounts of impurities.

Speaker wires

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 keep the resistance less than 0.10 Ω per wire?

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



Solution:

a. $R = \rho l/A$

you can solve this for A and then find the diameter:

$D = 2.1$ mm.

b. $V = IR = 0.40$ V.

Stretching changes resistance

Suppose a wire of resistance R could be stretched uniformly until it was twice its original length. What would happen to its resistance?

Solution:

The total volume of the wire should stay the same; therefore if the length doubles, the cross-sectional area A is halved.
This increases the resistance by a factor of 4.

QUICK QUIZ 4

Aliens with strange powers visit Earth and double every linear dimension of every object on the surface of the Earth. Does the electrical cord from the wall socket to your floor lamp now have (a) more resistance than before, (b) less resistance, or (c) the same resistance? Does the light bulb filament glow (d) more brightly than before, (e) less brightly, or (f) the same? (Assume the resistivities of materials remain the same before and after the doubling.)

QUICK QUIZ 4 ANSWER

(b), (d). The length of the line cord will double in this event. This would tend to increase the resistance of the line cord.
But the doubling of the radius of the line cord results in the increase of the cross-sectional area by a factor of 4. This would reduce the resistance more than the doubling of length increases it.
The net result is a decrease in resistance.
The same effect would occur for the light bulb filament. The lowered resistance would result in a larger current in the filament, causing it to glow more brightly.

QUICK QUIZ 5

A voltage ΔV is applied across the ends of a nichrome heater wire having a cross-sectional area *A* and length *L.*
The same voltage is applied across the ends of a second heater wire having a cross-sectional area *A* and length 2*L.*
Which wire gets hotter? (a) the shorter wire, (b) the longer wire, or (c) not enough information to say.

QUICK QUIZ 5 ANSWER

(a). The resistance of the shorter wire is half that of the longer wire. The power dissipated, $P = (\Delta V)^2/R$, (and hence the rate of heating) will be greater for the shorter wire. Consideration of the expression $P = I^2 R$ might initially lead one to think that the reverse would be true. However, one must realize that the currents will not be the same in the two wires.

Temperature Variation of Resistivity

- For most metals, resistivity increases with increasing temperature
  - With a higher temperature, the metal's constituent atoms vibrate with increasing amplitude
  - The electrons find it more difficult to pass the atoms

Temperature Variation of Resistivity

- For most metals, resistivity increases approximately linearly with temperature over a limited temperature range

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

  - ρ_o is the resistivity at some reference temperature T_o
    - T_o is usually taken to be 20° C
    - α is the *temperature coefficient of resistivity*

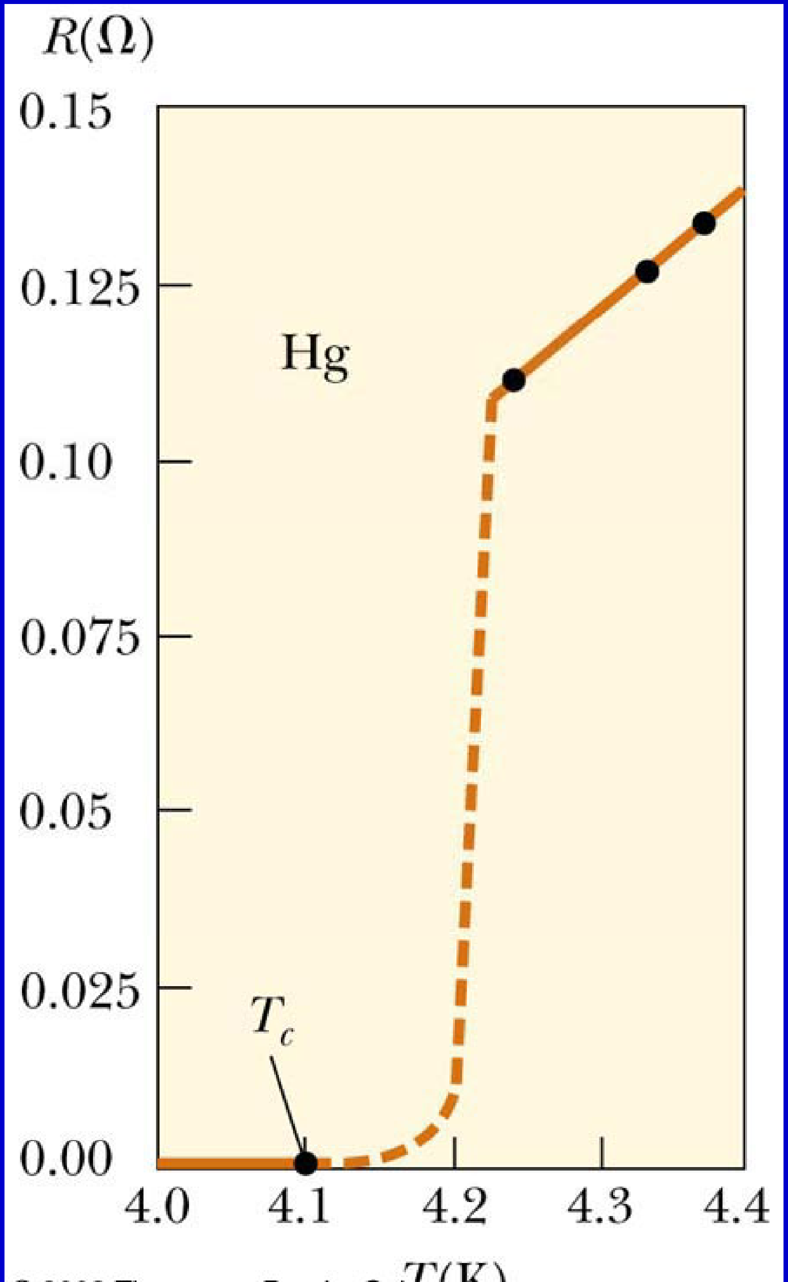
Temperature Variation of Resistance

- Since the resistance *R* of a conductor with uniform cross sectional area *A* is proportional to the resistivity ρ , you can find the effect of temperature on resistance

$$R = R_o[1 + \alpha(T - T_o)]$$

Superconductors

- A class of materials and compounds whose resistances fall to virtually zero below a certain temperature, T_C
  - T_C is called the *critical temperature*
- The graph suddenly drops to zero at T_C
- Once a current is set up in a superconductor, it persists without any applied voltage since R = 0



Electrical Energy and Power

- In a circuit, as a charge moves through the battery, the electrical potential energy of the system is increased by $\Delta Q \Delta V$
  - The chemical potential energy of the battery decreases by the same amount
- As the charge moves through a resistor, it loses this potential energy during collisions with atoms in the resistor
  - The temperature of the resistor will increase

Electrical Energy and Power

- The rate at which the energy is lost is the power

$$P = \frac{\Delta Q}{\Delta t}\Delta V = I\Delta V$$

- From Ohm's Law, alternate forms of power are

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

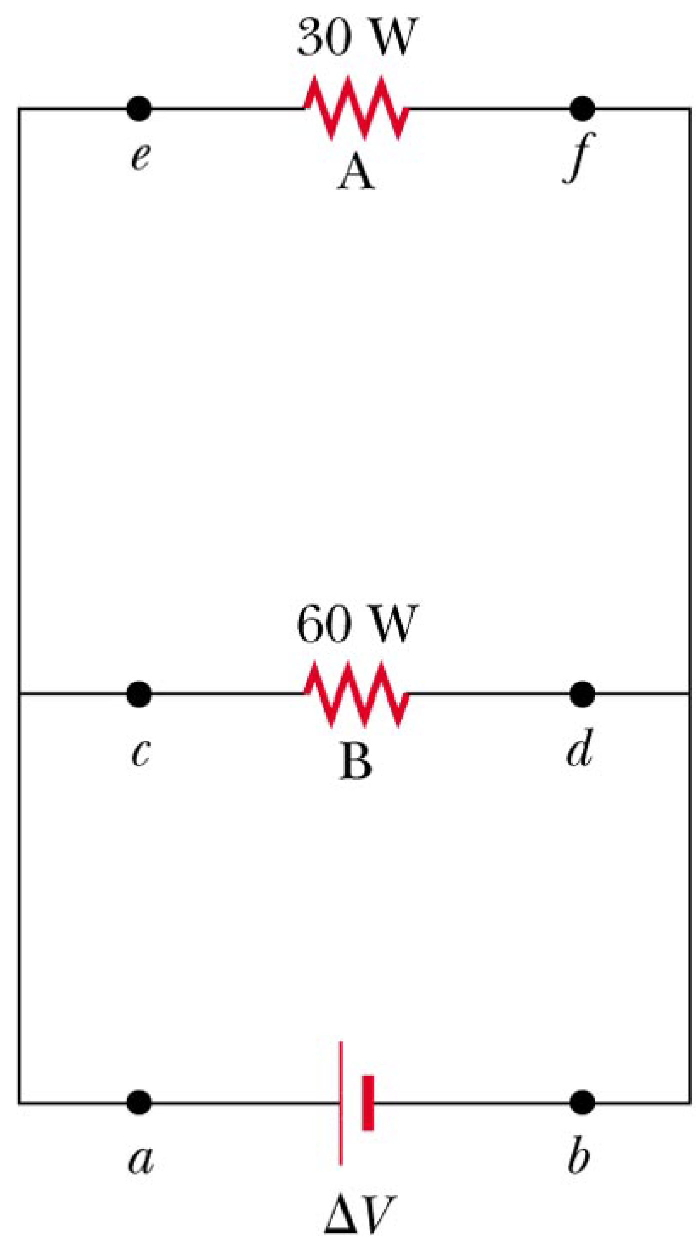
Electrical Energy and Power

- The SI unit of power is Watt (W)
  - I must be in Amperes, R in ohms and V in Volts
- The unit of energy used by electric companies is the *kilowatt-hour*
  - This is defined in terms of the unit of power and the amount of time it is supplied
  - 1 kWh = 3.60×10^6 J

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

QUICK QUIZ 6

For the two resistors shown here, rank the currents at points a through f, from largest to smallest.



QUICK QUIZ 6 ANSWER

$I_a = I_b > I_c = I_d > I_e = I_f$. Charges constituting the current I_a leave the positive terminal of the battery and then split to flow through the two bulbs; thus, $I_a = I_c + I_e$. Because the potential difference ΔV is the same across the two bulbs and because the power delivered to a device is $P = I(\Delta V)$, the 60–W bulb with the higher power rating must carry the greater current. Because charge does not accumulate in the bulbs, all the charge flowing into a bulb from the left has to flow out on the right; consequently $I_c = I_d$ and $I_e = I_f$. The two currents leaving the bulbs recombine to form the current back into the battery, $I_f + I_d = I_b$.

QUICK QUIZ 7

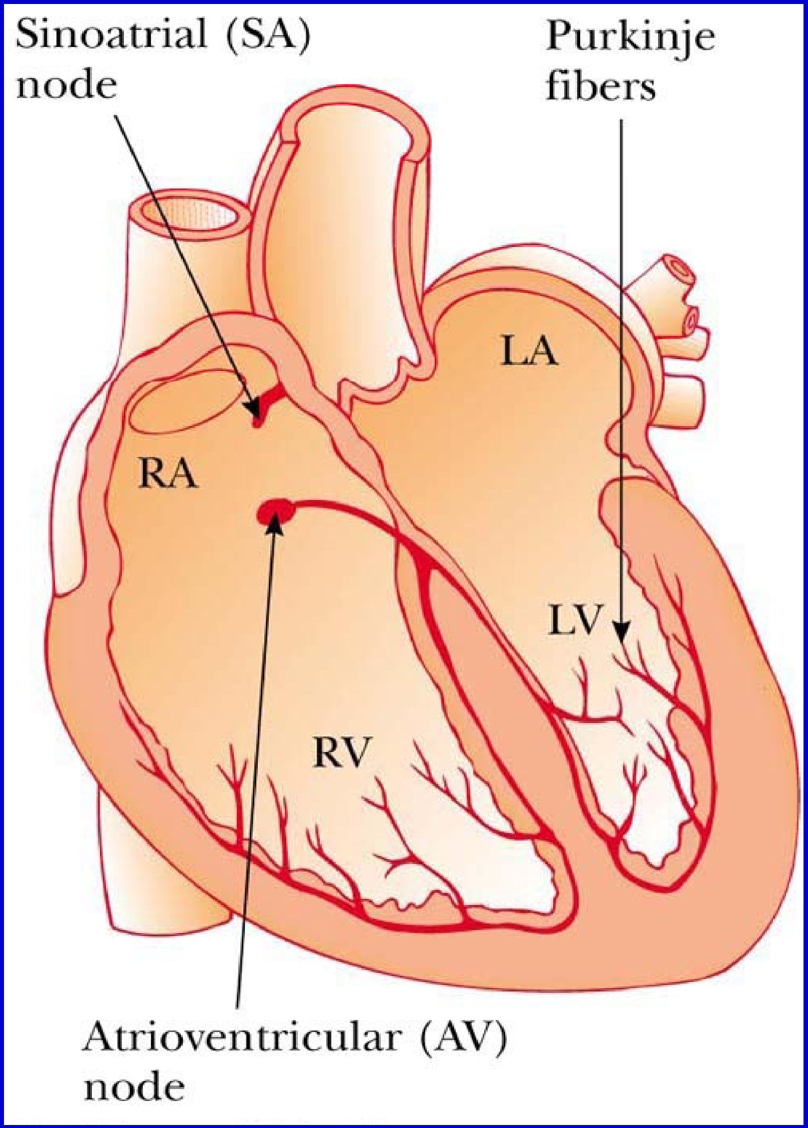
Two resistors, A and B, are connected across the same potential difference. The resistance of A is twice that of B. (a) Which resistor dissipates more power? (b) Which carries the greater current?

QUICK QUIZ 7 ANSWER

B, B. Because the voltage across each resistor is the same, and the rate of energy delivered to a resistor is $P = (\Delta V)^2/R$, the resistor with the lower resistance exhibits the higher rate of energy transfer. In this case, the resistance of B is smaller than that for A and thus B dissipates more power. Furthermore, because $P = I(\Delta V)$, the current carried by B is larger than that of A.

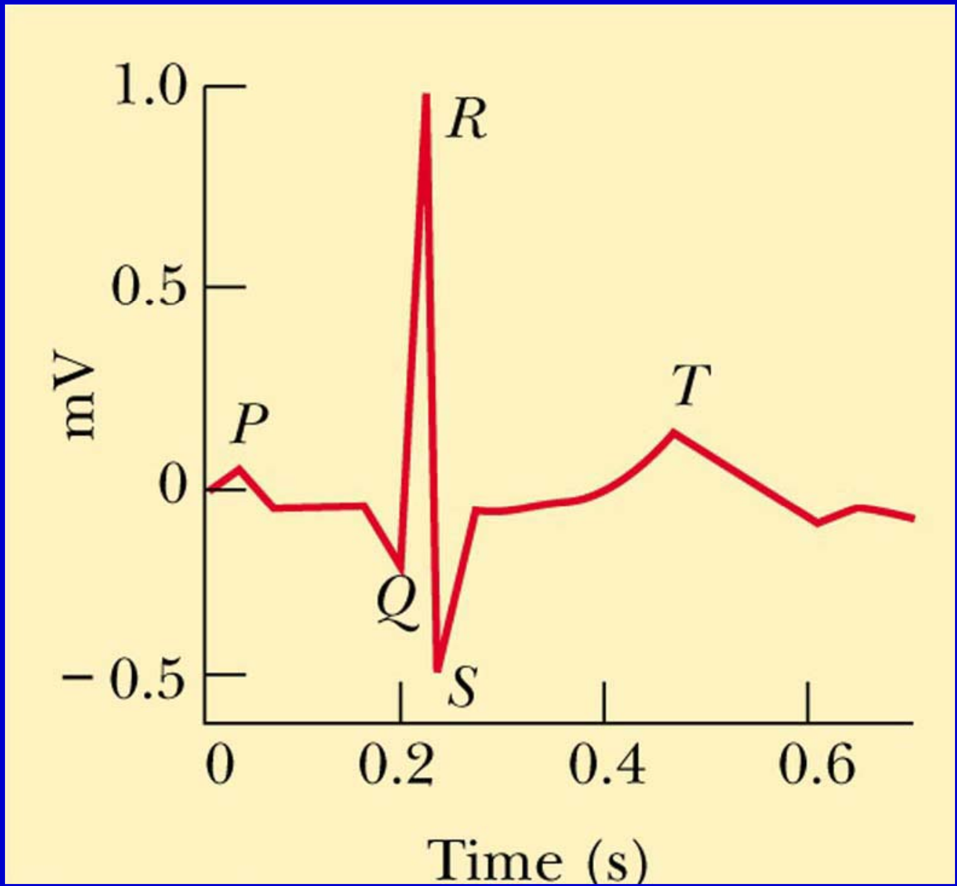
Electrical Activity in the Heart

- Every action involving the body's muscles is initiated by electrical activity
- Voltage pulses cause the heart to beat
- These voltage pulses are large enough to be detected by equipment attached to the skin



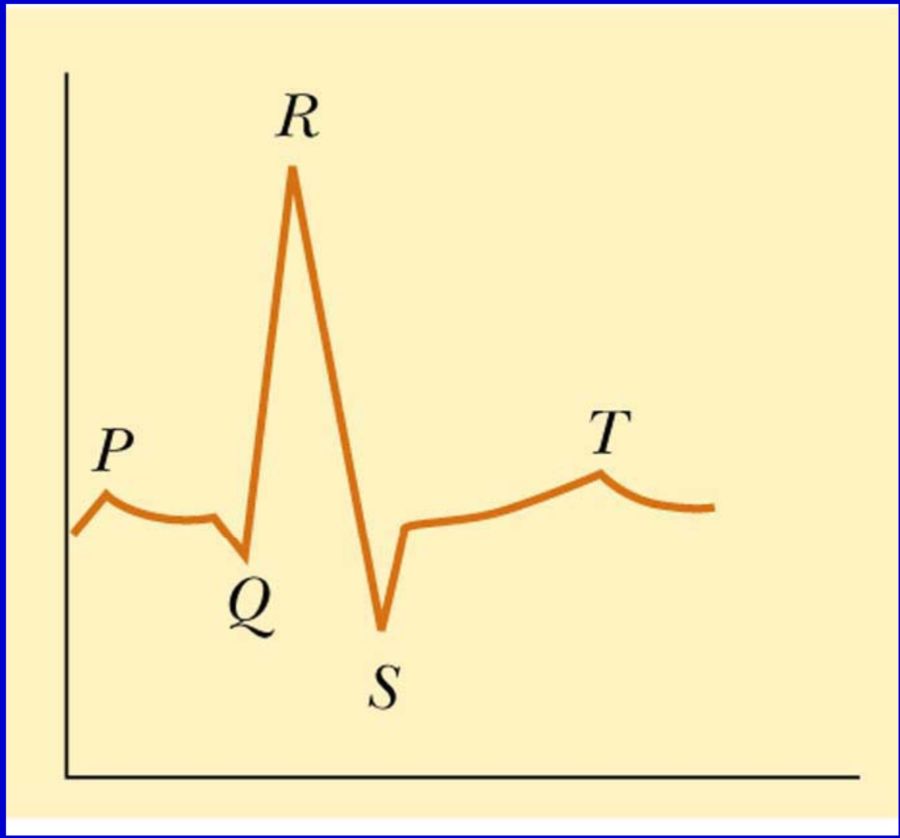
Electrocardiogram (EKG)

- A normal EKG
- P occurs just before the atria begin to contract
- The QRS pulse occurs in the ventricles just before they contract
- The T pulse occurs when the cells in the ventricles begin to recover

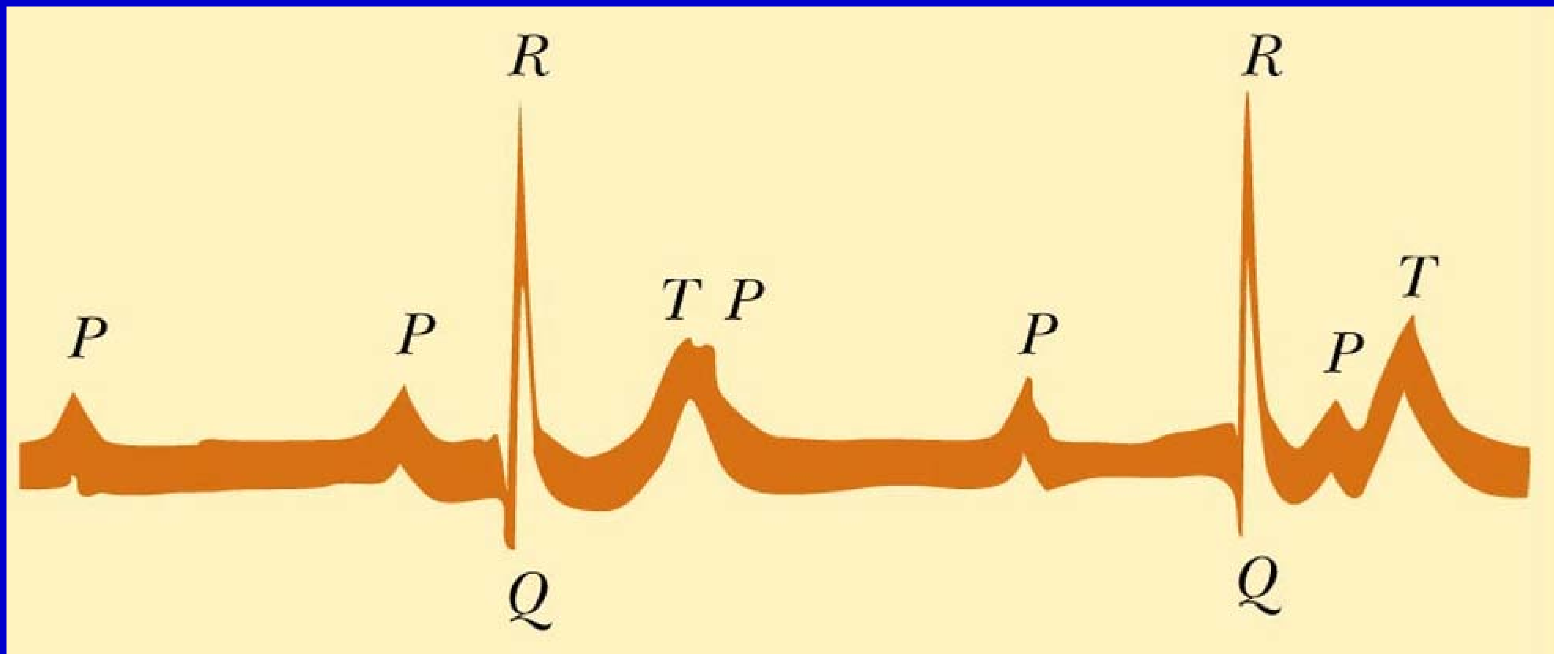


Abnormal EKG

- The QRS portion is wider than normal
- This indicates the possibility of an enlarged heart

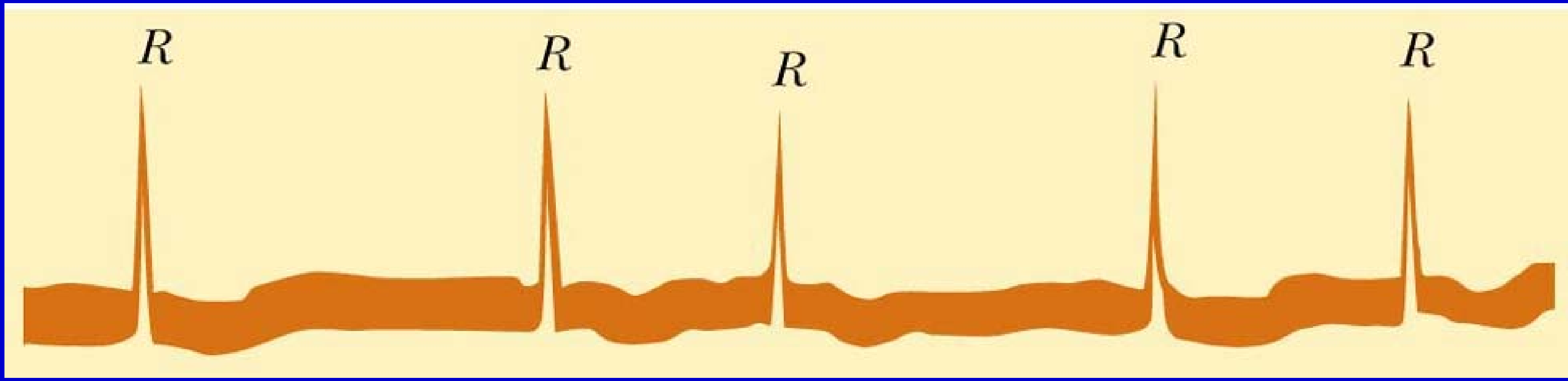


Abnormal EKG



- There is no constant relationship between P and QRS pulse
- This suggests a blockage in the electrical conduction path between the SA and the AV nodes
- This leads to inefficient heart pumping

Abnormal EKG



- No P pulse and an irregular spacing between the QRS pulses
- Symptomatic of irregular atrial contraction, called *fibrillation*
- The atrial and ventricular contraction are irregular

Implanted Cardioverter Defibrillator (ICD)

- Devices that can monitor, record and logically process heart signals
- Then supply different corrective signals to hearts that are not beating correctly