Chapter 17

Current and Resistance

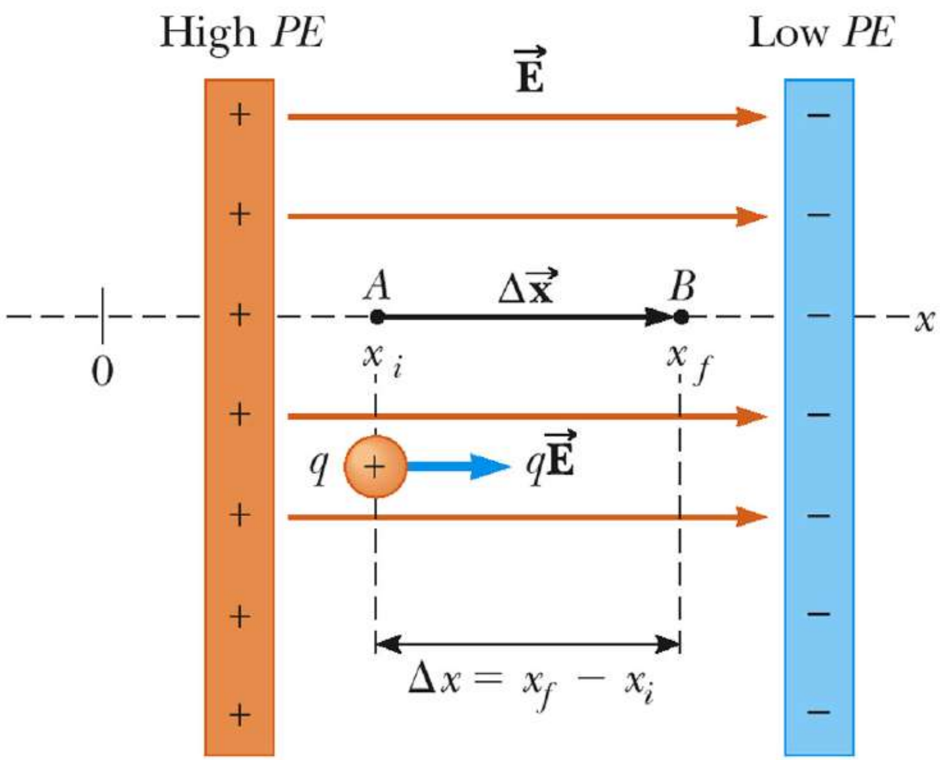
(With a hint of Chap. 16 *potential*)

Electric Potential Energy 16.1

- The electrostatic force is a conservative force
- It is possible to define an electrical potential energy function with this force
- Work done by a conservative force is equal to the negative of the change in potential energy

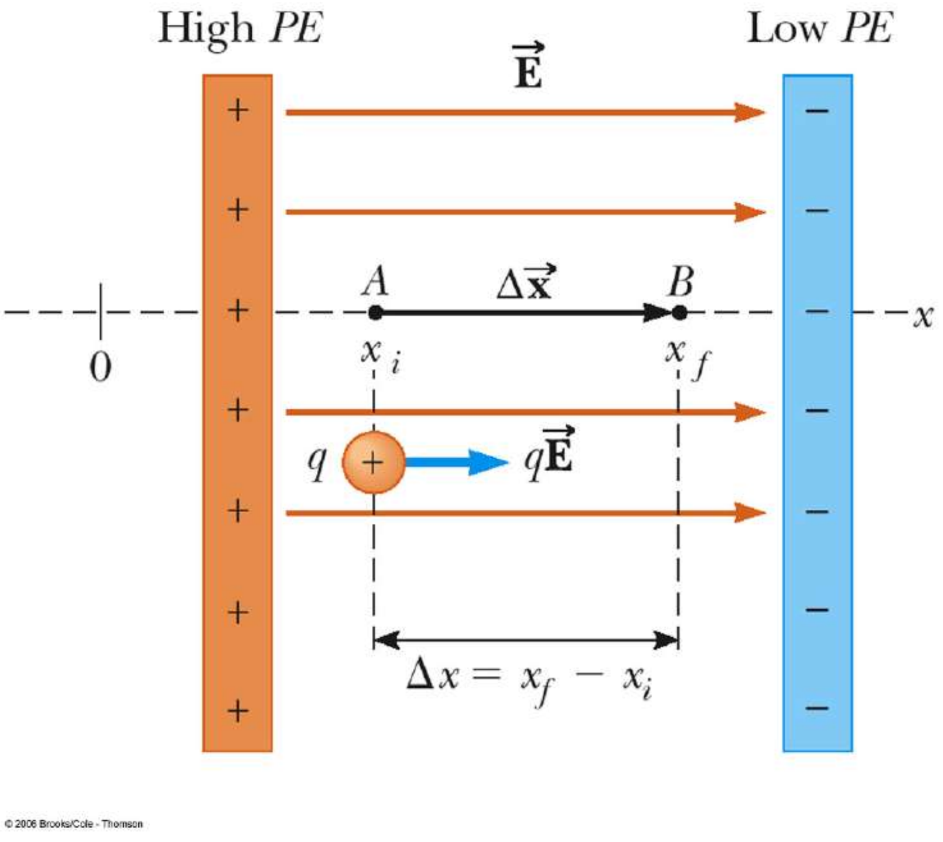
Work and Potential Energy

- There is a uniform field between the two plates
- As the charge moves from A to B, work is done on it
- $W = -\Delta PE$
- $W = Fd = q\,E_x\,(x_f - x_i)$

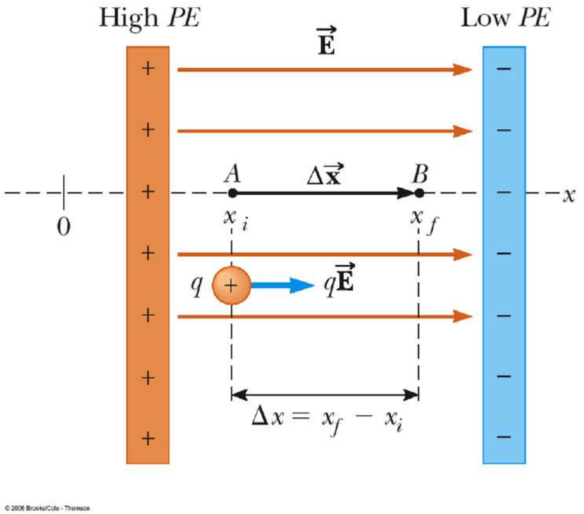


Work and Potential Energy

- A change in potential energy is evaluated by:
- $\Delta PE = -q E_x (x_f - x_i)$
  - only for a uniform field
- **Electrical potential energy** is due to its position in an electric field.



Work and Potential Energy



- Electrical potential energy is a component of mechanical energy.
- $ME = KE + PE_{grav} + PE_{elastic} + PE_{electric}$

Potential Difference

- **Electric Potential** equals the work that must be performed against electric forces to move a charge from a reference point to the point in question, divided by the charge.

electric potential: $V = \frac{PE_{electric}}{q}$

Potential Difference

- The potential difference between points A and B is defined as the change in the potential energy (final value minus initial value) of a charge q moved from A to B divided by the size of the charge
  - $\Delta V = V_B - V_A = \Delta PE / q$
- Potential difference is *not* the same as potential energy

Potential Difference

- $\Delta V = \Delta PE / q$
- Another way to relate the energy and the potential difference:
  - $\Delta PE = q \Delta V$

Potential Difference, cont.

- Both electric potential energy and potential difference are *scalar* quantities
- Units of potential difference
  - V = J/C
- A special case occurs when there is a *uniform electric field*
  - $\Delta V = -E_x \Delta x$
    - Gives more information about units: N/C = V/m

Sample Problem

Potential Energy and Potential Difference

A charge moves a distance of 2.0 cm in the direction of a uniform electric field whose magnitude is 215 N/C.As the charge moves, its electrical potential energy decreases by 6.9×10^{-19} J. Find the charge on the moving particle. What is the potential difference between the two locations?

Sample Problem, *continued*

Potential Energy and Potential Difference

Given:

$\Delta PE_{electric} = -6.9 \times 10^{-19}$ J

d = 0.020 m

E = 215 N/C

Unknown:

q = ?

ΔV = ?

Sample Problem, *continued*

Potential Energy and Potential Difference

Use the equation for the change in electrical potential energy.

$$PE_{electric} = -qEd$$

Rearrange to solve for *q*, and insert values.

$$q = \frac{\Delta PE_{electric}}{Ed} = \frac{(\ \ 6.9 \times 10^{19}\ \mathrm{J})}{(215\ \mathrm{N/C})(0.020\ \mathrm{m})}$$

$$\boxed{q = 1.6 \times 10^{19}\ \mathrm{C}}$$

Sample Problem, *continued*

Potential Energy and Potential Difference

The potential difference is the magnitude of *E* times the displacement.

$$\Delta V = Ed = (215\ \text{N/C})(0.020\ \text{m})$$

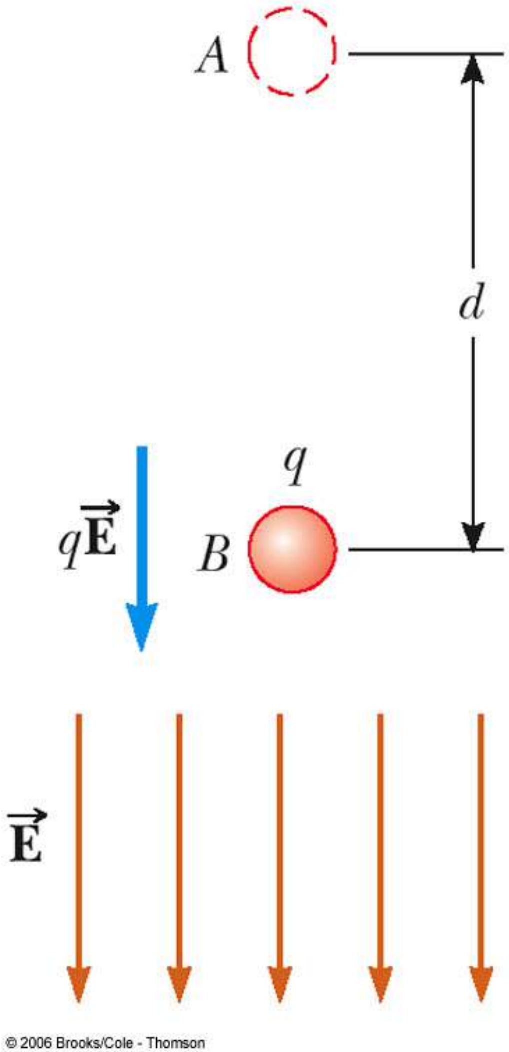
$$\boxed{\Delta V = 4.3\ \text{V}}$$

Energy and Charge Movements

- A positive charge gains electrical potential energy when it is moved in a direction opposite the electric field
- If a charge is released in the electric field, it experiences a force and accelerates, gaining kinetic energy
  - As it gains kinetic energy, it loses an equal amount of electrical potential energy
- A negative charge loses electrical potential energy when it moves in the direction opposite the electric field

Energy and Charge Movements, cont

- When the electric field is directed downward, point B is at a lower potential than point A
- A positive test charge that moves from A to B loses electric potential energy
- It will gain the same amount of kinetic energy as it loses in potential energy



Summary of Positive Charge Movements and Energy

- When a positive charge is placed in an electric field
  - It moves in the direction of the field
  - It moves from a point of higher potential to a point of lower potential
  - Its electrical potential energy decreases
  - Its kinetic energy increases

Summary of Negative Charge Movements and Energy

- When a negative charge is placed in an electric field
  - It moves opposite to the direction of the field
  - It moves from a point of lower potential to a point of higher potential
  - Its electrical potential energy increases
  - Its kinetic energy increases
  - Work has to be done on the charge for it to move from point A to point B

The Electron Volt 16.3

- The electron volt (eV) is defined as the energy that an electron gains when accelerated through a potential difference of 1 V
  - Electrons in normal atoms have energies of 10's of eV
  - Excited electrons have energies of 1000's of eV
  - High energy gamma rays have energies of millions of eV
- 1 eV = 1.6×10^{-19} J

Electric Current 17.1

- Whenever electric charges of like signs move, an *electric current* is said to exist
- The current is the **rate at which the charge flows through this surface**
  - Look at the charges flowing perpendicularly to a surface of area A

$$I \equiv \frac{\Delta Q}{\Delta t}$$

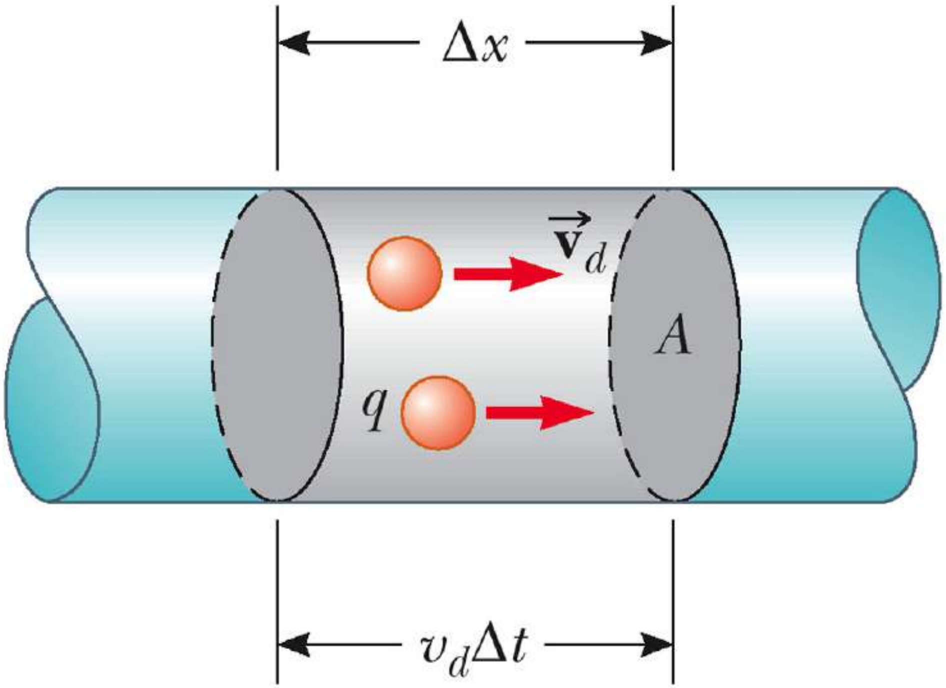
- The SI unit of current is Ampere (A)
  - 1 A = 1 C/s

Electric Current, cont

- The direction of the current is the direction positive charge would flow
  - This is known as *conventional current direction*
    - In a common conductor, such as copper, the current is due to the motion of the negatively charged electrons
- It is common to refer to a moving charge as a mobile *charge carrier*
  - A charge carrier can be positive or negative

Current and Drift Speed 17.2

- Charged particles move through a conductor of cross-sectional area A
- n is the number of charge carriers per unit volume
- n A Δx is the total number of charge carriers



Current and Drift Speed, cont

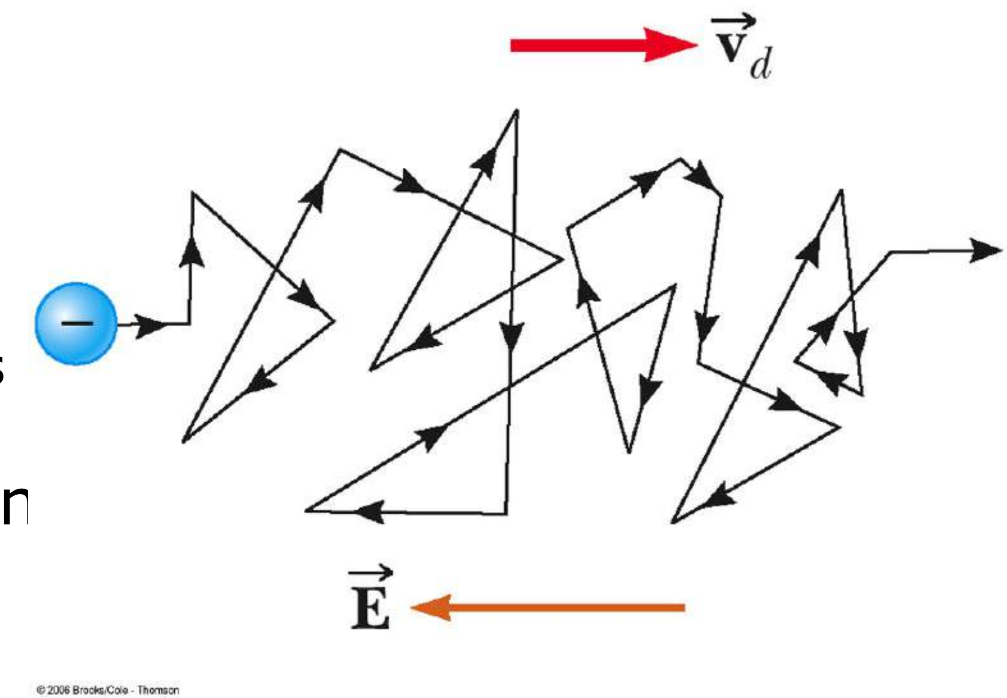
- The total charge is the number of carriers times the charge per carrier, q
  - $\Delta Q = (n\ A\ \Delta x)\ q$
- The drift speed, v_d, is the speed at which the carriers move
  - $v_d = \Delta x / \Delta t$
- Rewritten: $\Delta Q = (n\ A\ v_d\ \Delta t)\ q$
- Finally, current, $I = \Delta Q/\Delta t = nqv_dA$

Current and Drift Speed, final

- If the conductor is isolated, the electrons undergo random motion
- When an electric field is set up in the conductor, it creates an electric force on the electrons and hence a current

Charge Carrier Motion in a Conductor

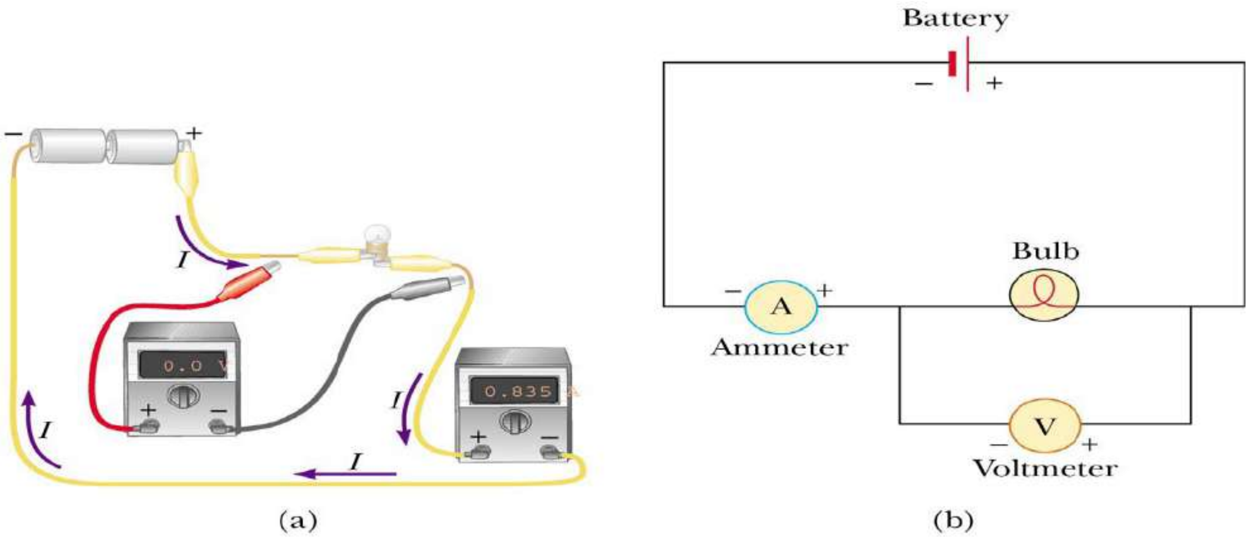
- The zig-zag black line represents the motion of charge carrier in a conductor
  - The net drift speed is small
- The sharp changes in direction are due to collisions
- The net motion of electrons is opposite the direction of the electric field



Electrons in a Circuit

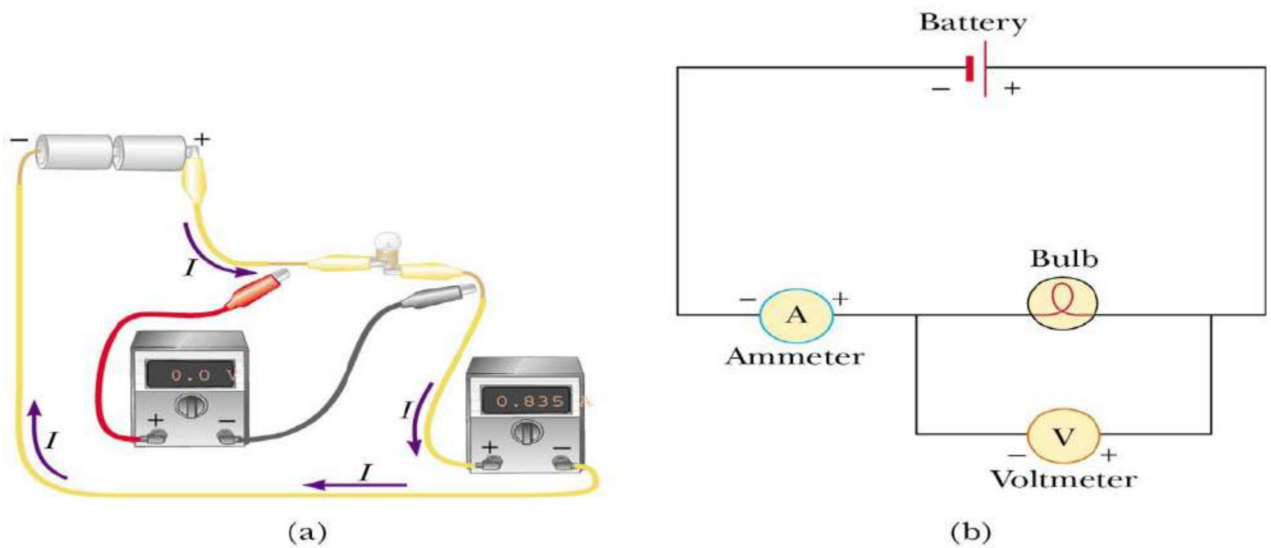
- The drift speed is much smaller than the average speed between collisions
- When a circuit is completed, the electric field travels with a speed close to the speed of light
- Although the drift speed is on the order of 10^{-4} m/s the effect of the electric field is felt on the order of 10^{8} m/s

Meters in a Circuit – Ammeter 17.3



- An <u>ammeter is used to measure current</u>
  - In line with the bulb, all the charge passing through the bulb also must pass through the meter

Meters in a Circuit – Voltmeter



- A voltmeter is used to measure voltage (potential difference)
  - Connects to the two ends of the bulb

Resistance 17.4

- 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 the ***resistance*** of the conductor

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

Resistance, cont

- 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

Georg Simon Ohm

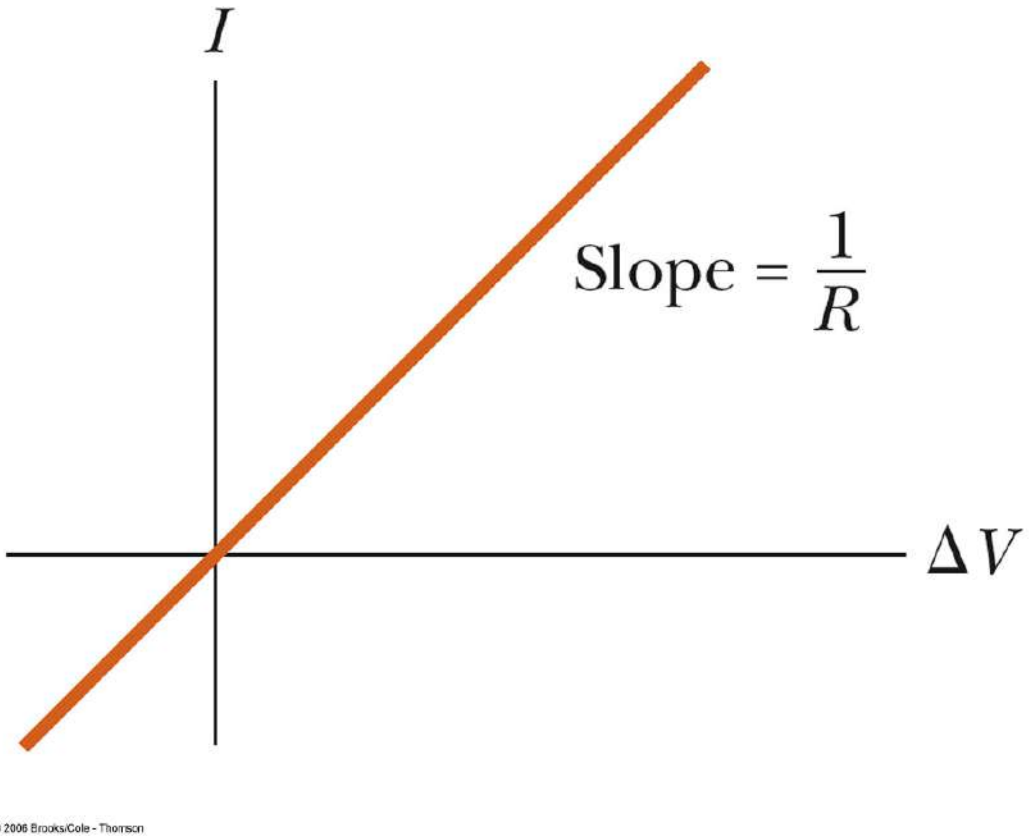
- 1787 – 1854
- Formulated the concept of resistance
- Discovered the proportionality between current and voltages

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*
  - $\Delta V = I R$
- 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*

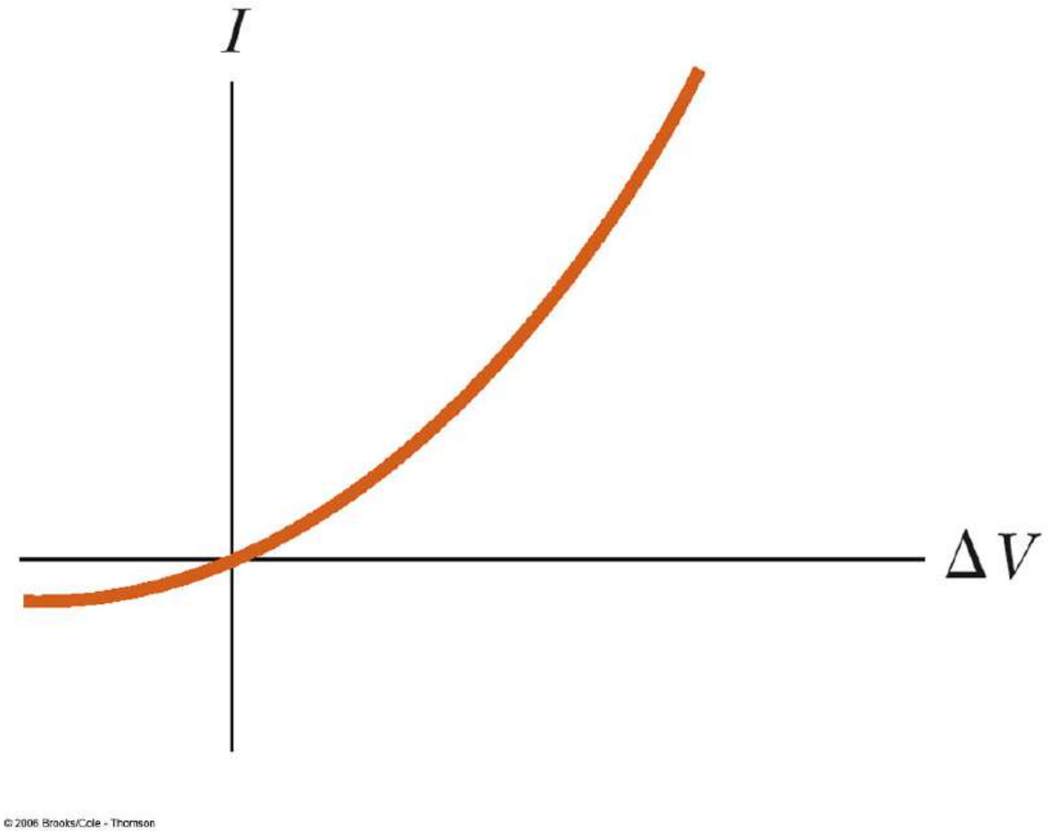
Ohm's Law, cont

- 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



Ohm’s Law, final

- 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



Resistivity 17.5

- 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
  - See table 17.1

Temperature Variation of Resistivity 17.6

- 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 through the atoms

Temperature Variation of Resistivity, cont

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

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

  - ρ is the resistivity at some temperature T
  - 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**

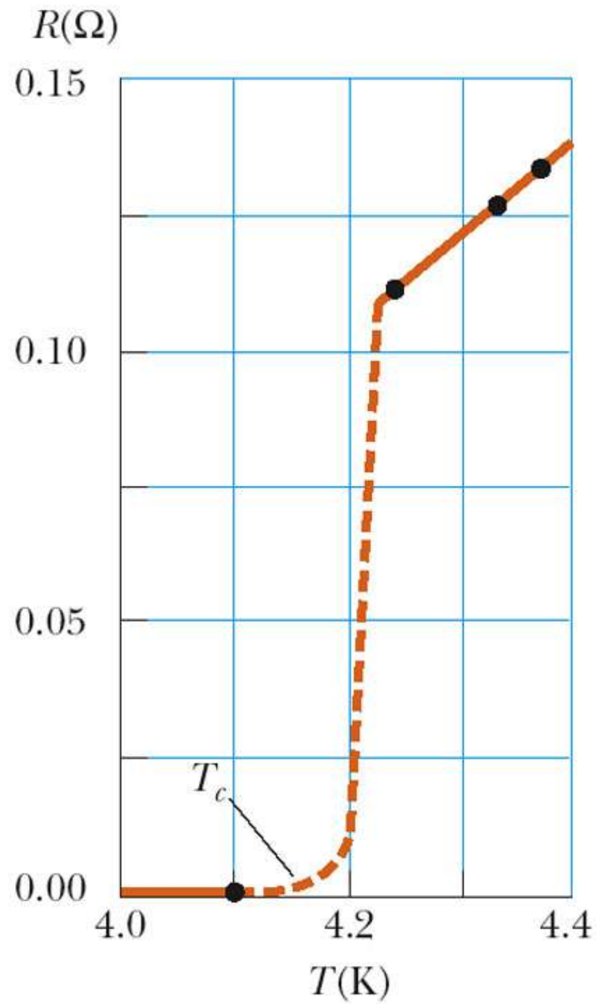
Temperature Variation of Resistance

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

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

Superconductors 17.7

- 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 is the same as a normal metal above T_C, but suddenly drops to zero at T_C



Superconductors, cont

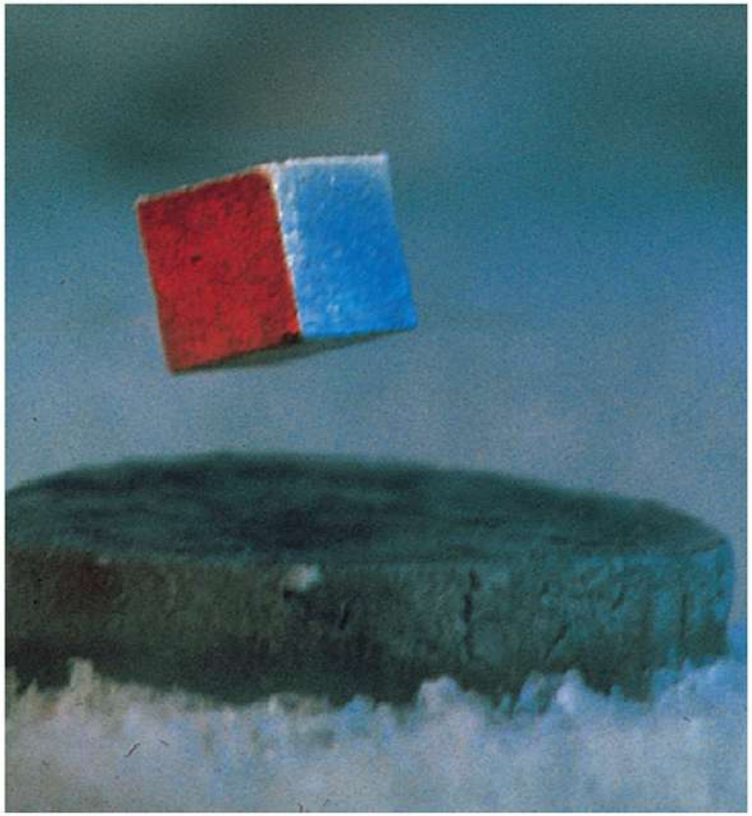
- The value of T_C is sensitive to
  - Chemical composition
  - Pressure
  - Crystalline structure
- Once a current is set up in a superconductor, it persists without any applied voltage
  - Since $R = 0$

Superconductor Timeline

- 1911
  - Superconductivity discovered by H. Kamerlingh Onnes
- 1986
  - High temperature superconductivity discovered by Bednorz and Müller
  - Superconductivity near 30 K
- 1987
  - Superconductivity at 96 K and 105 K
- Current
  - More materials and more applications

Superconductor, final

- Good conductors do not necessarily exhibit superconductivity
- One application is superconducting magnets

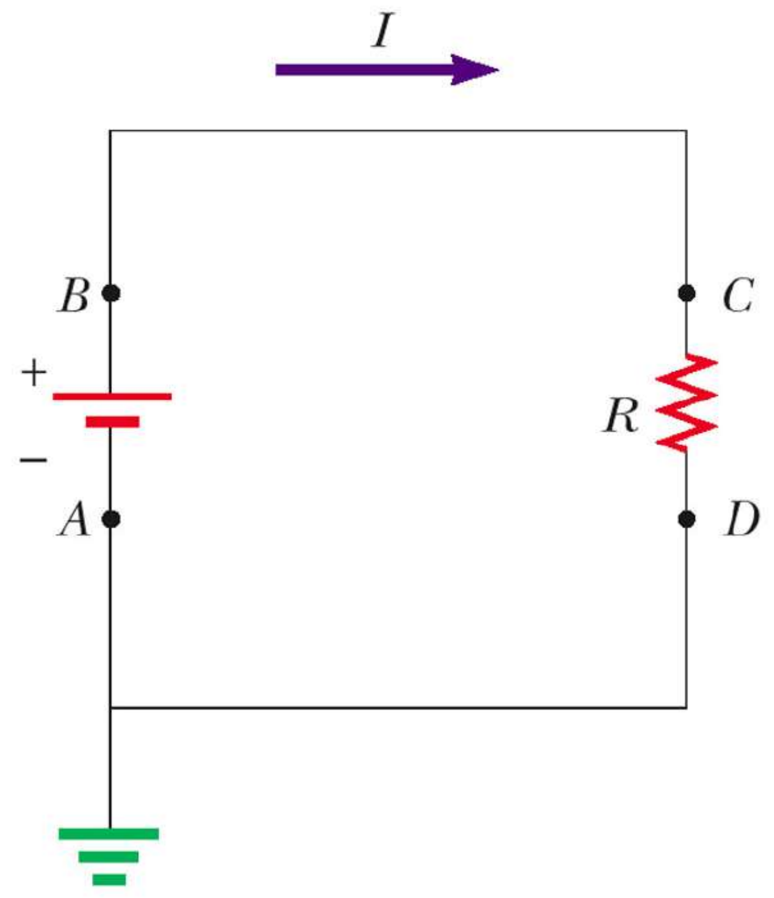


Electrical Energy and Power 17.8

- 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

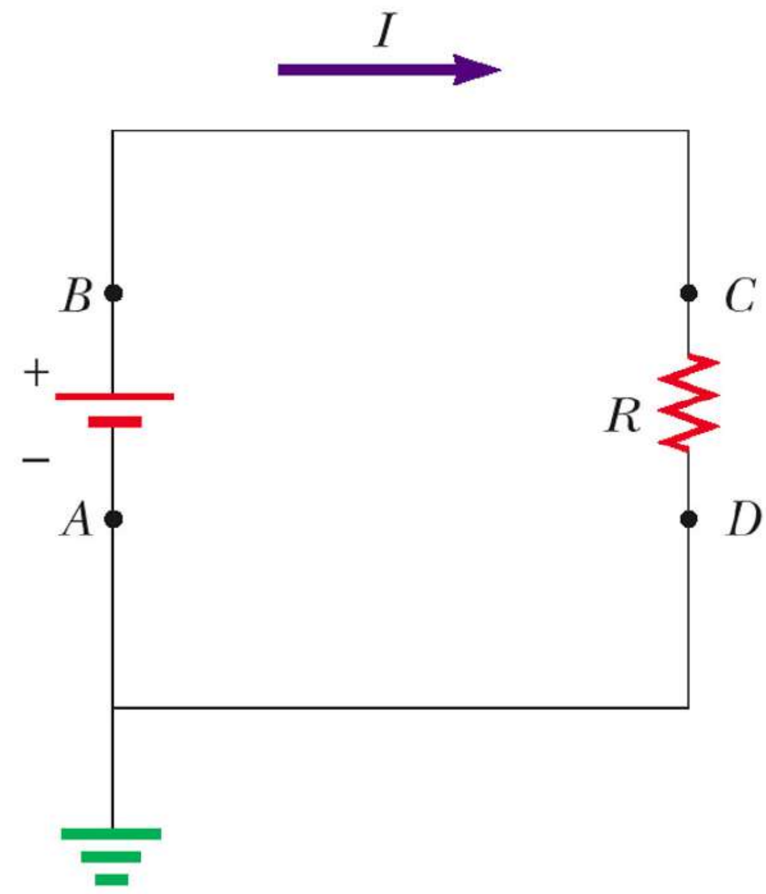
Energy Transfer in the Circuit

- Consider the circuit shown
- Imagine a quantity of positive charge, ΔQ, moving around the circuit from point A back to point A



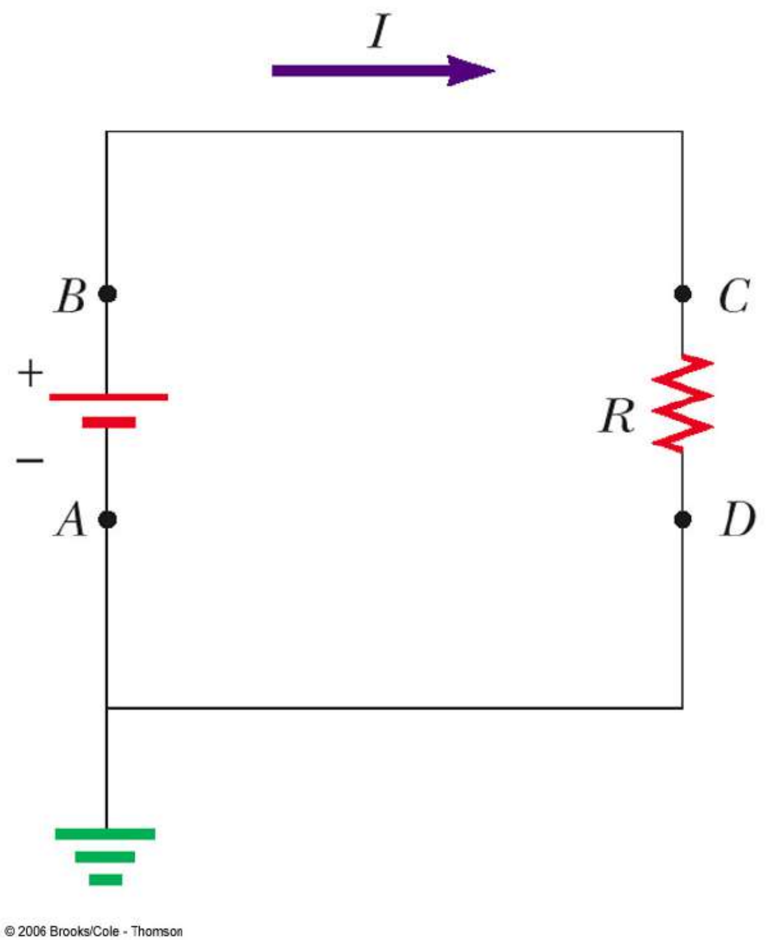
Energy Transfer in the Circuit, cont

- Point A is the reference point
  - It is grounded and its potential is taken to be zero
- As the charge moves through the battery from A to B, the potential energy of the system increases by $\Delta Q \Delta V$
  - The chemical energy of the battery decreases by the same amount



Energy Transfer in the Circuit, final

- As the charge moves through the resistor, from C to D, it loses energy in collisions with the atoms of the resistor
- The energy is transferred to internal energy
- When the charge returns to A, the net result is that some chemical energy of the battery has been delivered to the resistor and caused its temperature to rises



Electrical Energy and Power, cont

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

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

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

$$\wp = I^2 R = \frac{\Delta V^2}{R}$$

Electrical Energy and Power, final 17.9

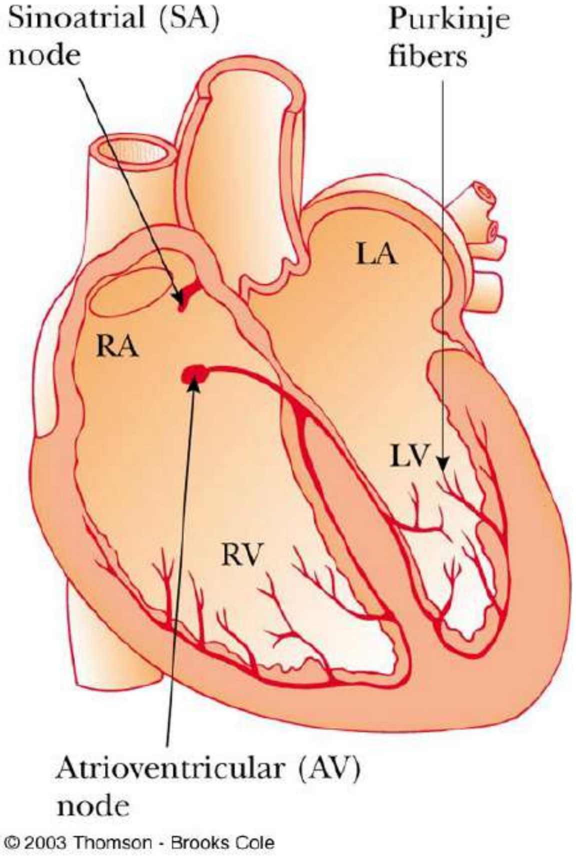
- The SI unit of power is Watt (W)
  - I must be in Amperes, R in ohms and ΔV in Volts
- The unit of energy used by electric companies is the *kilowatt-hour*
  - This is defined in terms of the unit of power and the amount of time it is supplied
  - 1 kWh = 3.60×10^6 J

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

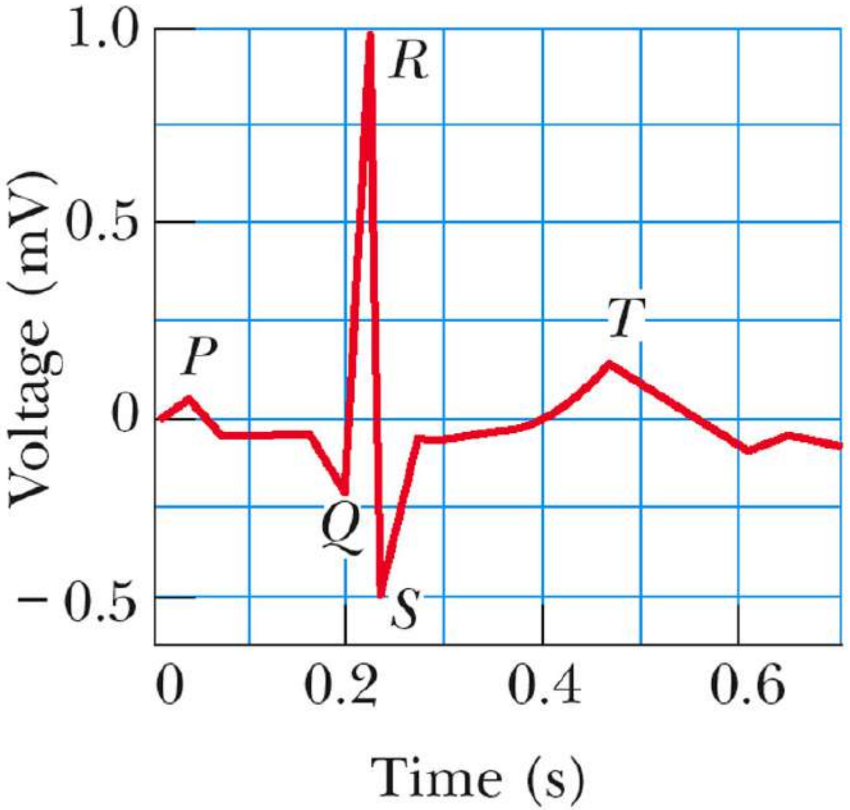
Operation of the Heart

- The sinoatrial (SA) node initiates the heartbeat
- The electrical impulses cause the right and left artial muscles to contract
- When the impulse reaches the atrioventricular (AV) node, the muscles of the atria begin to relax
- The ventricles relax and the cycle repeats



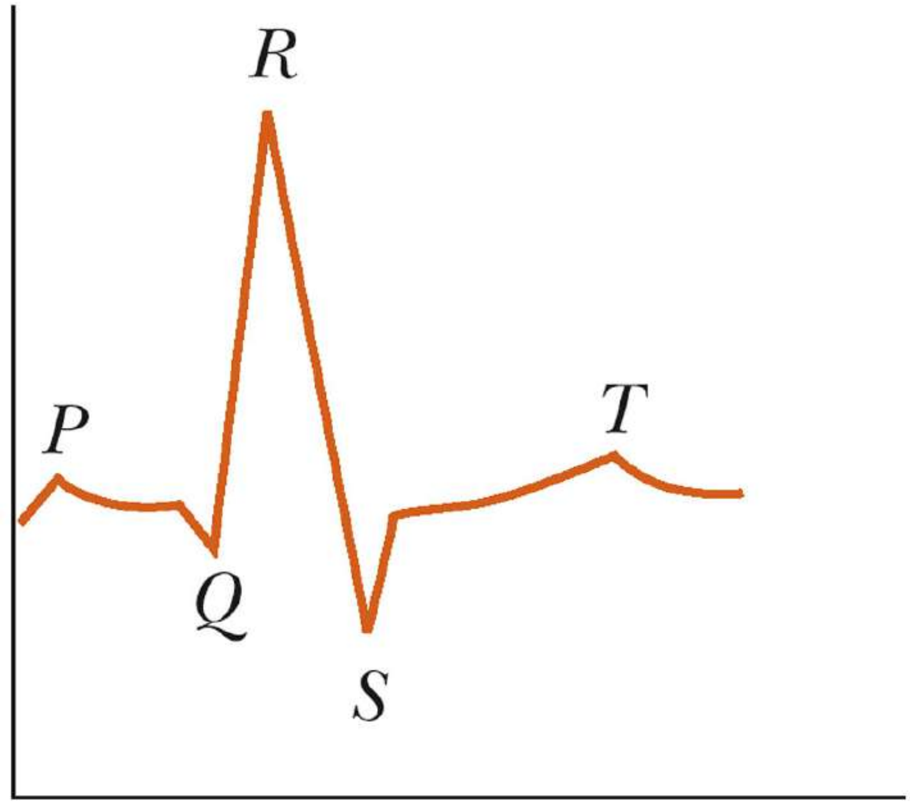
Electrocardiogram (EKG)

- 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

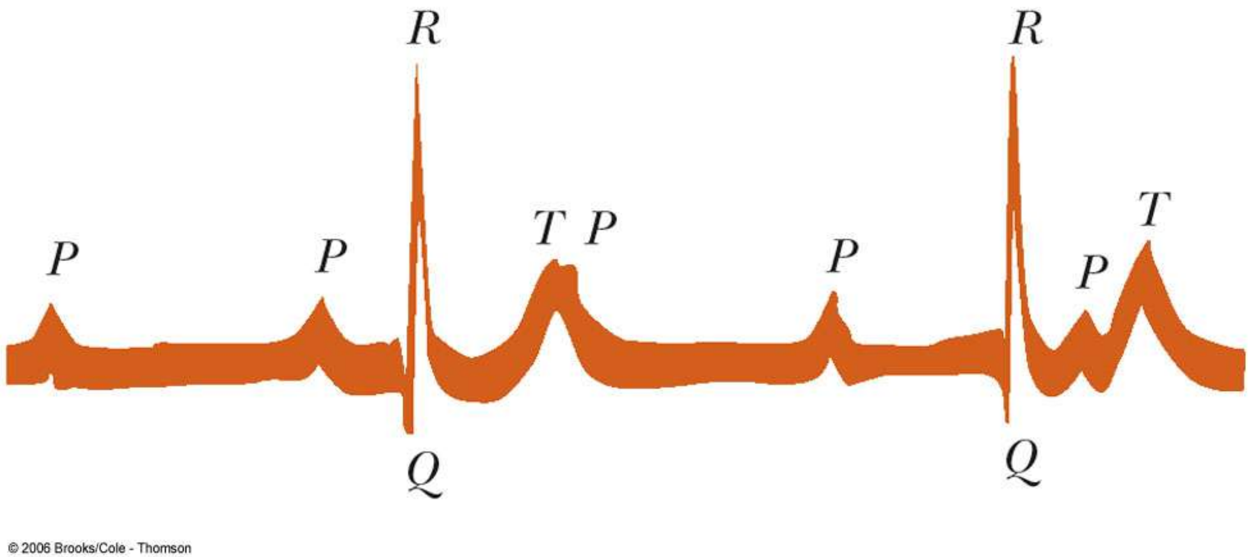


Abnormal EKG, 1

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

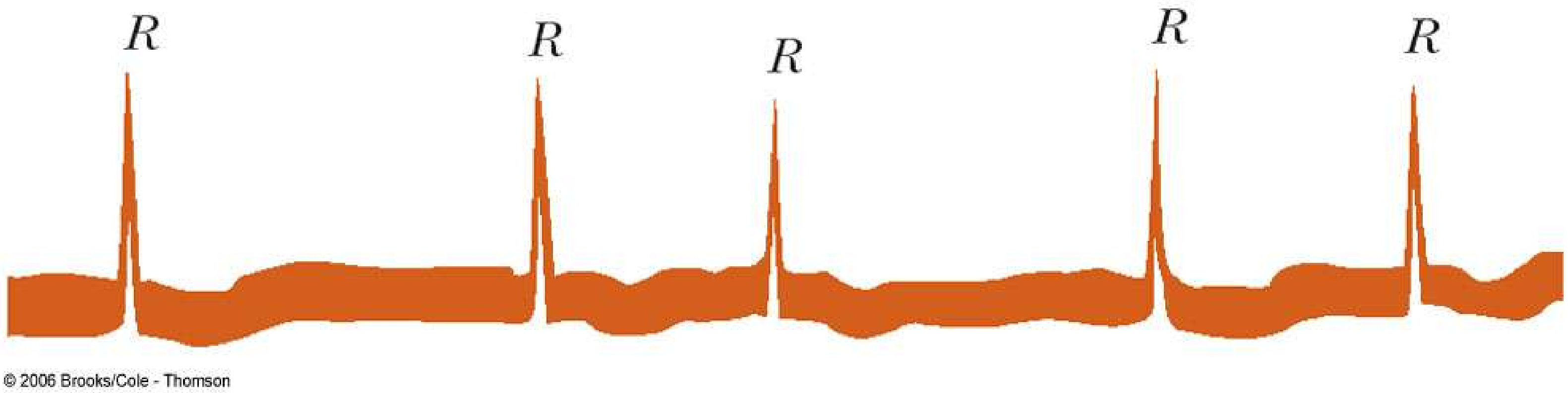


Abnormal EKG, 2



- 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

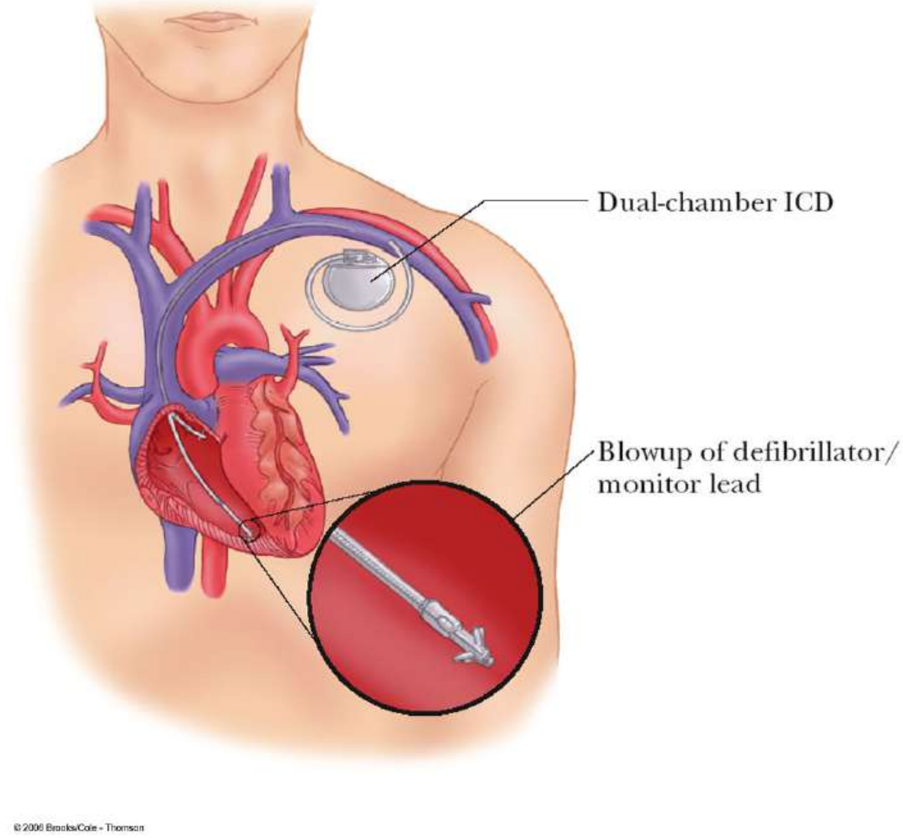
Abnormal EKG, 3



- 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



Functions of an ICD

- Monitor artrial and ventricular chambers
  - Differentiate between arrhythmias
- Store heart signals for read out by a physician
- Easily reprogrammed by an external magnet

More Functions of an ICD

- Perform signal analysis and comparison
- Supply repetitive pacing signals to speed up or show down a malfunctioning heart
- Adjust the number of pacing pulses per minute to match patient’s activity