PHYS 1444 – Section 003
Lecture #10

Thursday Sep. 27, 2012

Ian Howley for Dr. Andrew Brandt

Chapter 25

- Current
- Resistance
- Ohm's Law
- Resistivity
- Electric Power
- Alternating Current

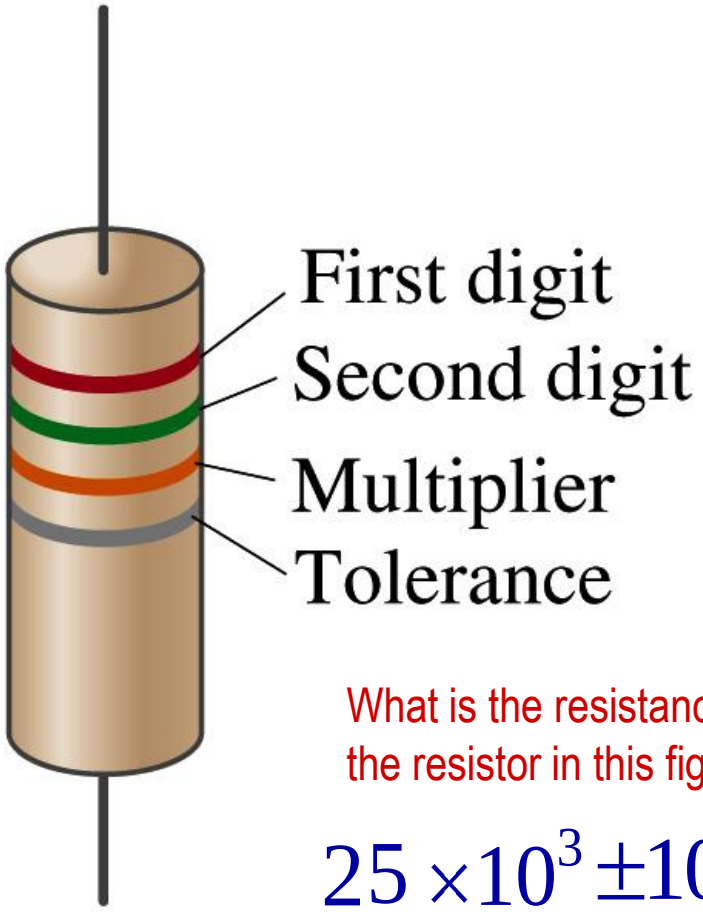
Ohm's Law: Resistors

- All electric devices offer resistance to the flow of current.
  - Filaments of light bulbs or heaters are wires with high resistance causing electrons to lose their energy in the wire
  - In general connecting wires have low resistance compared to other devices in the circuit
- In circuits, resistors are used to control the amount of current
  - Resistors offer resistance of less than one ohm to millions of ohms
  - Main types are
    - "wire-wound" resistors which consists of a coil of fine wire
    - "composition" resistors which are usually made of semiconductor carbon
    - thin metal films
- When drawn in the circuit, the symbol for a resistor is: 
- Wires are drawn simply as straight lines

Ohm's Law: Resistor Values

- Resistors have their resistance color-coded on its body
- The color-coding follows the convention below:

Color	Number	Multiplier	Tolerance
Black	0	$1=10^0$	
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%
None			20%

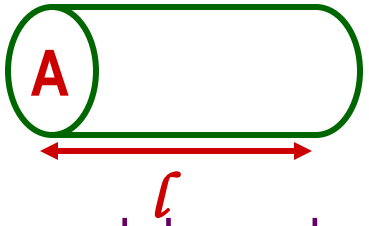


What is the resistance of the resistor in this figure?

$25 \times 10^3 \pm 10\%$

Resistivity

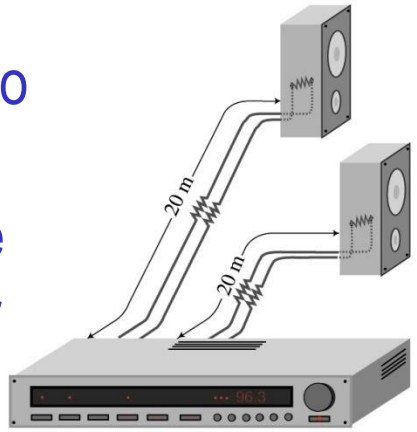
- It is experimentally found that the resistance R of a metal wire is directly proportional to its length ℓ and inversely proportional to its cross-sectional area A
  - How would you formularize this? $R = \rho \frac{l}{A}$



  - The proportionality constant ρ is called the **resistivity** and depends on the material used. What is the unit of this constant?
    - ohm-m or Ω–m
    - The values depends on material, purity, temperature, etc
  - How would you interpret the resistivity?
    - The higher the resistivity the higher the resistance
    - The lower the resistivity the lower the resistance and the higher the conductivity ➔ Silver has a very low resistivity.
      - So silver is one of the best conductors
  - The reciprocal of the resistivity is called the **conductivity**, σ, $\sigma = \frac{1}{\rho}$

Example 25 – 4

Speaker wires: Suppose you want to connect your stereo to remote speakers. (a) If each wire must be 20m long, what diameter copper wire should you use to keep the resistance less than 0.1 Ω per wire? (b) If the current on each speaker is 4.0A, what is the voltage drop across each wire?



The resistivity of copper is $\rho_{Cu} = 1.68 \times 10^{-8}\,\Omega \cdot m$ **Table 25.1**

From the formula for resistance, we can obtain the area

$$R = \rho \frac{l}{A}$$ Solve for A $$A = \rho \frac{l}{R} = \pi r^2$$

Solve for d $$d = 2r = 2\sqrt{\frac{\rho l}{\pi R}} = 2\sqrt{\frac{1.68 \times 10^{-8}\,\Omega \cdot m \cdot 20m}{\pi \cdot 0.1\Omega}} = 2.1 \times 10^{-3}\,m = 2.1mm$$

From Ohm's law, V=IR, we obtain

$$V = IR = 4.0A \cdot 0.1\Omega = 0.4V$$

Example 25 – 5

Stretching changes resistance: A wire of resistance R is stretched uniformly until it is twice its original length. What happens to its resistance?

What is the constant quantity in this problem? The volume!

What is the volume of a cylinder of length L and radius r? $V = AL = \pi r^2 L$

What happens to A if L increases by a factor two, L'=2L?

The cross-sectional area, A, halves. A'=A/2

The original resistance is $R = \rho \frac{l}{A}$

The new resistance is $R' = \rho \frac{L'}{A'} = \rho \frac{2L}{A/2} = 4\rho \frac{L}{A} = 4R$

The resistance of the wire increases by a factor four if the length is doubled (fixed V).

Temperature Dependence of Resistivity

- Do you think the resistivity depends on temperature?
  - Yes (or at least you should!)
- Would it increase or decrease with the temperature?
  - Increase
  - Why?
  - Since the atoms are vibrating more rapidly as temperature increases and are arranged in a less orderly fashion. So?
    - They might interfere more with the flow of electrons.
- If the temperature change is not too large, the resistivity of metals usually increase nearly linearly w/ temperature

$$\rho_T = \rho_0 \left[1 + \alpha \ T - T_0 \right]$$

  - α is the temperature coefficient of resistivity
  - α of some semiconductors can be negative due to the increased number of free electrons.

Electric Energy

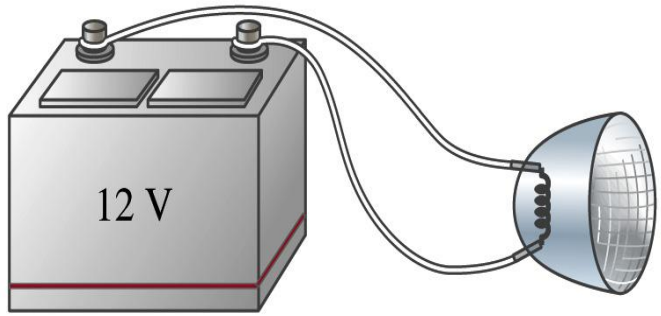
- Why is electric energy useful?
  - It can be transformed easily into different forms of energy:
    - Motors, pumps, etc, transform electric energy to mechanical energy
    - Heaters, dryers, cook-tops, etc., transform electricity to thermal energy
    - Light bulb filaments transform electric energy to light energy
      - Only about 10% of the energy turns to light with 90% lost via heat
      - Typical household light bulb and heating elements have resistance of order few ohms to few hundred of ohms
- How does electric energy transform to thermal energy?
  - Flowing electrons collide with the vibrating atoms of the wire.
  - In each collision, part of electron's kinetic energy is transferred to the atom it collides with.
  - The kinetic energy of wire's atoms increases, and thus the temperature of the wire increases.
  - The increased thermal energy can be transferred as heat through conduction and convection to the air in a heater or to food in a pan; it can also be radiated as light.

Electric Power

- How do we find out the power of an electric device?
  - What is definition of the power?
    - The rate at which work is done or the energy is transferred
- What energy is transferred when an infinitesimal charge dq moves through a potential difference V?
  - dU=Vdq
  - If dt is the time required for an amount of charge dq to move through the potential difference V, the power P is
  - $P = dU/dt = V\,dq/dt$ ← **What is this?**
  - Thus, we obtain $P = IV$. **In terms of resistance** $P = I^2R = \frac{V^2}{R}$
  - What is the unit? **Watts = J/s**
  - What kind of quantity is the electrical power?
    - Scalar
  - P=IV can apply to any device, while the formulae involving resistance only applies to Ohmic resistors.

Example 25 – 7

Headlights: Calculate the resistance of a 40-W automobile headlight designed for a 12V battery.



40-W Headlight

Since the power is 40W and the voltage is 12V, we use the formula with V and R.

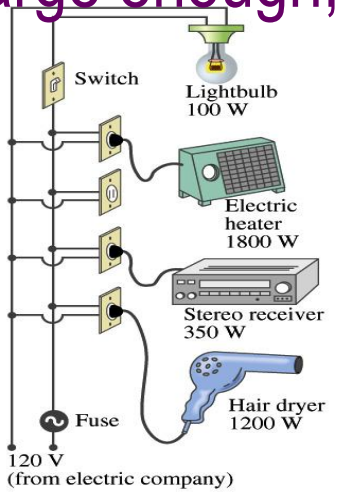
$$P = \frac{V^2}{R}$$

Solve for R

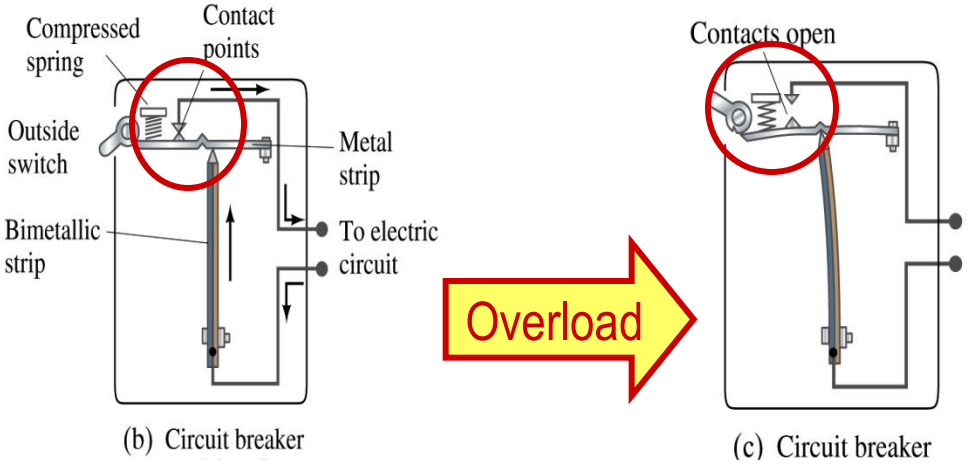
$$R = \frac{V^2}{P} = \frac{12V^{\ 2}}{40W} = 3.6\Omega$$

Power in Household Circuits

- Household devices usually have small resistance
  - But since they draw current, if they become large enough, wires can heat up (overload) and cause a fire
    - Why is using thicker wires safer?
      - Thicker wires has less resistance, lower heat



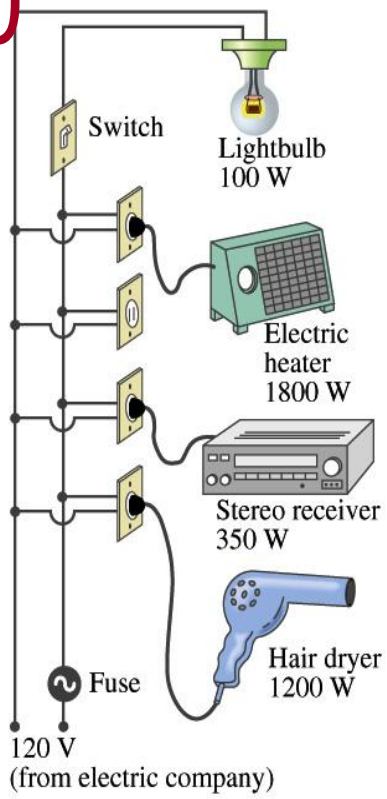
- How do we prevent this?
  - Put in a switch that disconnects the circuit when overloaded
    - Fuse or circuit breakers
    - They open up the circuit when the current exceeds a certain value



Example 25 – 10

Will a 30A fuse blow?

Determine the total current drawn by all the devices in the circuit in the figure.



The total current is the sum of current drawn by the individual devices.

$P = IV$ Solve for I $I = P/V$

Bulb $I_B = 100W/120V = 0.8A$

Heater $I_H = 1800W/120V = 15.0A$

Stereo $I_S = 135W/120V = 2.9A$

Dryer $I_D = 1200W/120V = 10.0A$

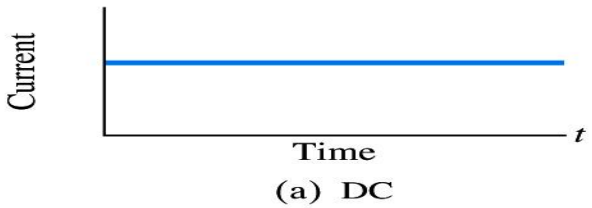
Total current

$$I_T = I_B + I_H + I_S + I_D = 0.8A + 15.0A + 2.9A + 10.0A = 28.7A$$

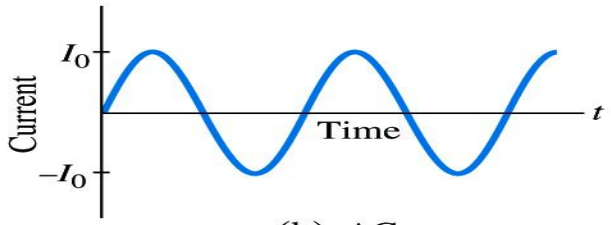
What is the total power? $P_T = P_B + P_H + P_S + P_D = 100W + 1800W + 350W + 1200W = 3450W$

Alternating Current

- Does the direction of the flow of current change when a battery is connected to a circuit?
  - No. Why?
    - Because its source of potential difference is constant.
  - This kind of current is called the Direct Current (DC
    - How would DC look as a function of time?
      - A horizontal line
- Electric generators at electric power plant produce alternating current (AC)
  - AC reverses direction many times a second
  - AC is sinusoidal as a function of time
- Most currents supplied to homes and business are AC.



(a) DC

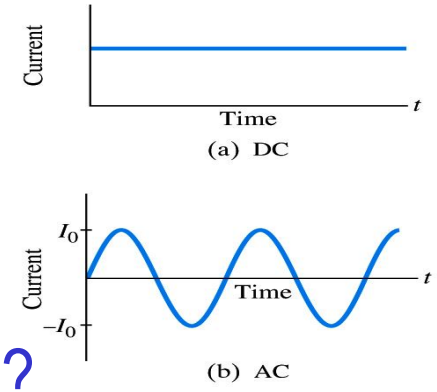


(b) AC

Alternating Current

- The voltage produced by an AC electric generator is sinusoidal
  - This is why the current is sinusoidal
- Voltage produced can be written as

$$V = V_0 \sin 2\pi ft = V_0 \sin \omega t$$



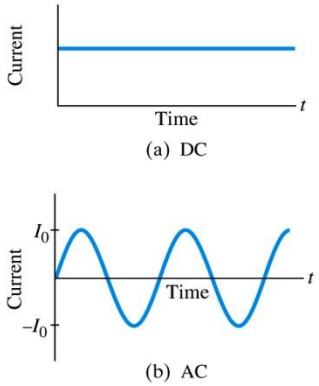
- What are the maximum and minimum voltages?
  - V_0 and $-V_0$
  - The potential oscillates between $+V_0$ and $-V_0$, the peak voltages or amplitude
  - What is f?
    - The frequency, the number of complete oscillations made per second. What is the unit of f? What is the normal size of f in the US?
      - f = 60 Hz in the US and Canada.
      - Many European countries have f = 50Hz.
  - $\omega = 2\pi f$

Alternating Current

- Since V=IR, if a voltage V exists across a resistance R, the current I is

$$I = \frac{V}{R} = \frac{V_0}{R}\sin 2\pi ft = I_0 \sin \omega t$$

What is this?



- What are the maximum and minimum currents?
  - I_0 and $-I_0$
  - The current oscillates between $+I_0$ and $-I_0$, the peak currents or amplitude. The current is positive when electron flows in one direction and negative when they flow in the opposite direction.
  - What is the average current?
    - Zero. So there is no power and no heat produced in a heater?
      - Wrong! The electrons actually flow back and forth, so power is delivered.