PHYS 1444 – Section 501
Lecture #10

Monday, Feb. 27, 2006
Dr. Jaehoon Yu

- Ohm's Law: Resisters
- Resistivity
- Electric Power
- Alternating Current
- Power Delivered by AC

Announcements

- How was the exam?
  - Will be done by this Wednesday
- Reading assignments
  - CH25 – 8 through CH 25 – 10

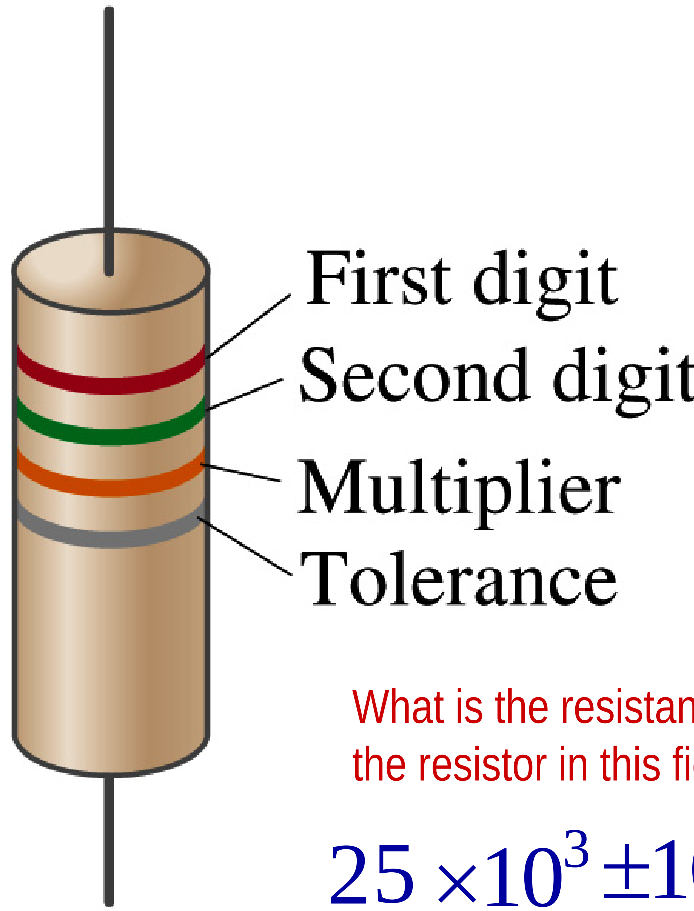
Ohm's Law: Resistors

- All electric devices offer resistance to the flow of current.
  - Filaments of light bulbs or heaters are wires with high resistance to cause electrons to lose their energy in the wire
  - In general connecting wires have low resistance compared to other devices on 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 its 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%

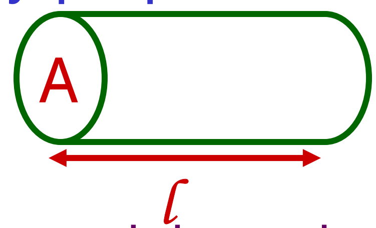


What is the resistance of the resistor in this figure?

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

Resistivity

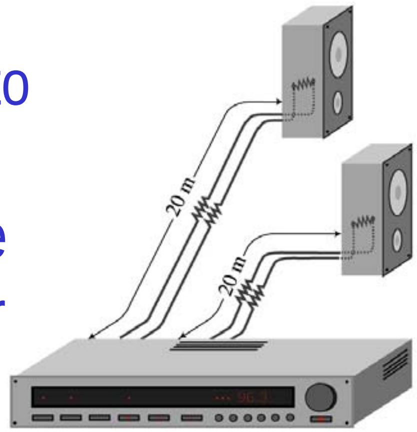
- It is experimentally found that the resistance R of a metal wire is directly proportional to its length ℓ and inversely proportional to its cross-sectional area A
  - How would you formularize this? $$R = \rho \frac{l}{A}$$



  - The proportionality constant ρ is called the <u>resistivity</u> and depends on the material used. What is the unit of this constant?
    - ohm-m or Ω–m
    - The values depends on purity, heat treatment, 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 the lowest resistivity.
      - So the silver is the best conductor
  - The reciprocal of the resistivity is called the <u>conductivity</u>, 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 a copper is $\rho_{Cu} = 1.68\times10^{-8}\,\Omega\cdot m$ Table 25.1

From the formula for resistance, we can obtain the formula for area

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

Solve for d

$$d = 2r = 2\sqrt{\frac{\rho l}{\pi R}} = 2\sqrt{\frac{1.68\times10^{-8}\,\Omega\cdot m\cdot 20m}{\pi\cdot 0.1\Omega}} = 2.1\times10^{-3}m = 2.1mm$$

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 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 of four if the length increases twice.

Temperature Dependence of Resistivity

- Do you think the resistivity depends on temperature?
  - Yes
- 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

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

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

Electric Power

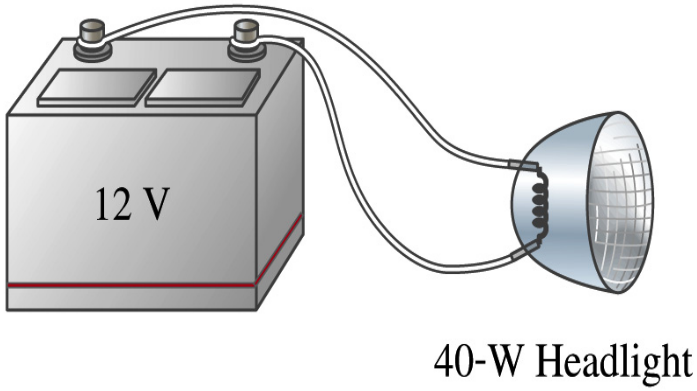
- Why is the electric energy useful?
  - It can transform into different forms of energy easily.
    - Motors, pumps, etc, transform electric energy to mechanical energy
    - Heaters, dryers, cook-tops, etc, transforms electricity to thermal energy
    - Light bulb filament transforms electric energy to light energy
      - Only about 10% of the energy turns to light and the 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 transforms 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 on a pan, through radiation to bread in a toaster or radiated as light.

Electric Power

- How do we find out the power transformed by an electric device?
  - What is definition of the power?
    - The rate at which work is done or the energy is transformed
- What is the energy transformed 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 $P = VI$. In terms of resistance $P = I^2 R = \frac{V^2}{R}$
  - What is the unit? Watts = J/s
  - What kind of quantity is the electrical power?
    - Scalar
  - P=IV can apply to any devices while the formula with resistance can only apply to resistors.

Example 25 – 7

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



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

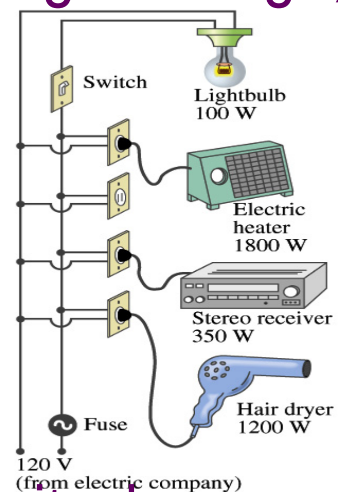
$$P = \frac{V^2}{R}$$

Solve for R

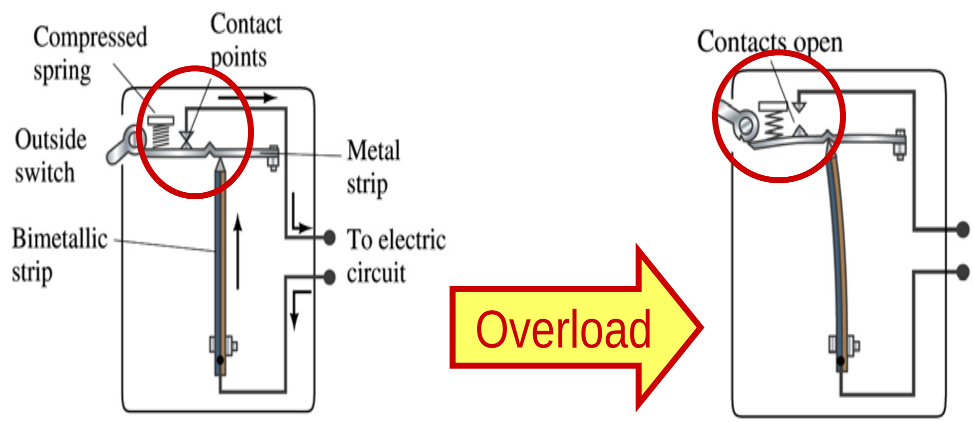
$$R = \frac{V^2}{P} = \frac{(12V)^2}{40W} = 3.6\Omega$$

Power in Household Circuits

- Household devices usually have small resistance
  - But since they draw current, if they become large enough, wires can heat up (overloaded)
    - Why is using thicker wires safer?
      - Thicker wires has less resistance, lower heat
  - Overloaded wire can set off a fire at home



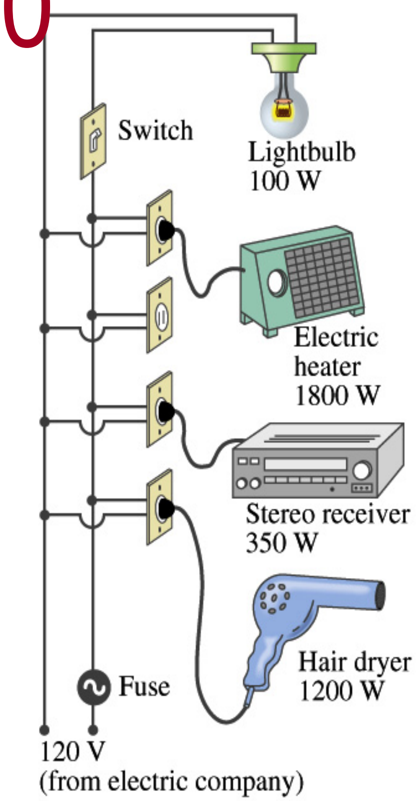
- How do we prevent this?
  - Put in a switch that would disconnect the circuit when overloaded
    - Fuse or circuit breakers
    - They open up the circuit when the current is over certain value



(b) Circuit breaker (closed)

(c) Circuit breaker (open)

Example 25 – 10



Will a fuse blow?: Calculate 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 individual device.

$P = IV$ **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 $I_D = 1200W/120V = 10.0A$

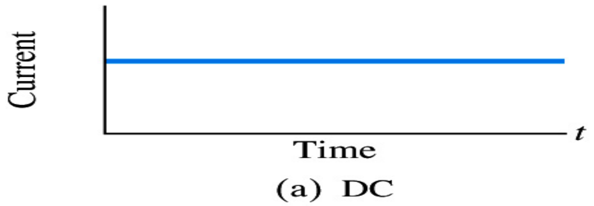
Total current

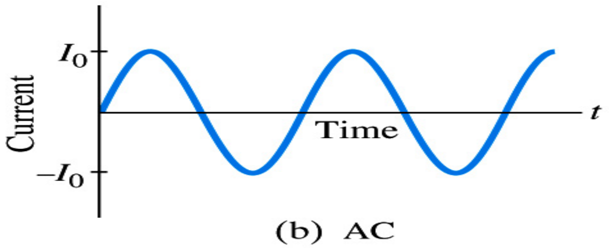
$$I_T = I_B + I_H + I_S + I_D = 0.8A + 15.0A + 2.9A + 10.0A = 28.7A$$

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 stays put.
  - This kind of current is called the Direct Current (DC), and it does not change its direction of flow.
    - How would DC look as a function of time?
      - A straight 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 the currents supplied to homes and business are AC.

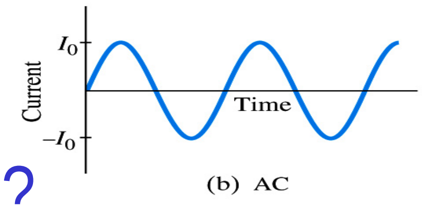




Alternating Current

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

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



- 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=60Hz 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

What is this?

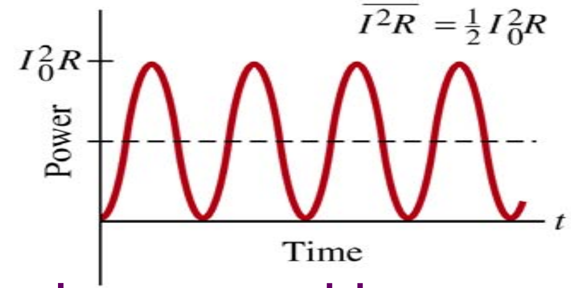
$$I = \frac{V}{R} = \frac{V_0}{R}\sin 2\pi ft = I_0 \sin \varpi t$$

- 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 to one direction and negative when they flow opposite.
  - AC is as many times positive as negative. What's the average current?
    - Zero. So there is no power and no heat is produced in a heater?
      - Yes there is! The electrons actually flow back and forth, so power is delivered.

Power Delivered by Alternating Current

- AC power delivered to a resistance is:

$$P = I^2 R = I_0^2 R \sin^2 \varpi t$$



  – Since the current is squared, the power is always positive

- The average power delivered is $\overline{P} = \frac{1}{2} I_0^2 R$
- Since the power is also P=V^2/R, we can obtain

$$P = \left(V_0^2 / R\right) \sin^2 \varpi t$$

Average power

$$\overline{P} = \frac{1}{2}\left(\frac{V_0^2}{R}\right)$$

- The average of the square of current and voltage are important in calculating power:

$$\overline{I^2} = \frac{1}{2} I_0^2 \qquad \overline{V^2} = \frac{1}{2} V_0^2$$

Power Delivered by Alternating Current

- The square root of each of these are called root-mean-square, or rms:

$$I_{rms} = \sqrt{\overline{I^2}} = \frac{I_0}{\sqrt{2}} = 0.707 I_0$$

$$V_{rms} = \sqrt{\overline{V^2}} = \frac{V_0}{\sqrt{2}} = 0.707 V_0$$

- rms values are sometimes called effective values
  - These are useful quantities since they can substitute current and voltage directly in power, as if they are in DC

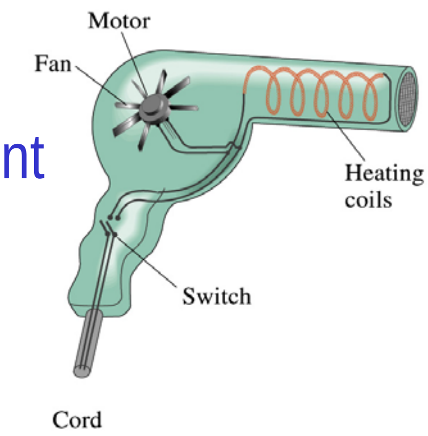
$$\overline{P} = \frac{1}{2} I_0^2 R = I_{rms}^2 R$$

$$\overline{P} = \frac{1}{2} \frac{V_0^2}{R} = \frac{V_{rms}^2}{R}$$

$$\overline{P} = I_{rms} V_{rms}$$

  - In other words, an AC of peak voltage V_0 or peak current I_0 produces as much power as DC voltage of V_{rms} or DC current I_{rms}.
  - So normally, rms values in AC are specified or measured.
    - US uses 115V rms voltage. What is the peak voltage?
    - $V_0 = \sqrt{2} V_{rms} = \sqrt{2} \cdot 115V = 162.6V$
    - Europe uses 240V
    - $V_0 = \sqrt{2} V_{rms} = \sqrt{2} \cdot 240V = 340V$

Example 25 – 11



Hair Dryer. (a) Calculate the resistance and the peak current in a 1000-W hair dryer connected to a 120-V AC line. (b) What happens if it is connected to a 240-V line in Britain?

The rms current is: $I_{rms} = \dfrac{\overline{P}}{V_{rms}} = \dfrac{1000W}{120V} = 8.33A$

The peak current is: $I_0 = \sqrt{2} I_{rms} = \sqrt{2} \cdot 8.33A = 11.8A$

Thus the resistance is: $R = \dfrac{\overline{P}}{I_{rms}^2} = \dfrac{1000W}{(8.33A)^2} = 14.4\Omega$

(b) If connected to 240V in Britain …

The average power provide by the AC in UK is

$$\overline{P} = \frac{V_{rms}^2}{R} = \frac{(240V)^2}{14.4\Omega} = 4000W$$

So? The heating coils in the dryer will melt!