PHYS 1444 – Section 004
Lecture #10

Monday, Feb. 20, 2012
Dr. Jaehoon Yu

- Electric Current and Resistance
- The Battery
- Ohm's Law: Resisters
- Resistivity
- Electric Power
- Alternating Current
- Power Delivered by AC

Today's homework is #6, due 10pm, Tuesday, Feb. 28!!

Announcements

- First term exam
  - 5:30 – 6:50pm, this Wednesday, Feb. 22
  - SH103
  - CH21.1 through 24.6, plus appendices A and B
- Reading assignments
  - CH24.6
- Colloquium this week
  - 4pm Wednesday, SH101
    - Dr. G. Fiete, UTAustin
  - Mark your calendar on triple credit colloquium on April 4.
    - Dr. Youngkee Kim

Physics Department
The University of Texas at Arlington
COLLOQUIUM

Recent developments in the study of topological phases of matter

Dr. Greg Fiete

University of Texas at Austin

4:00 pm Wednesday February 22, 2012 room 101 SH

Abstract:

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In this talk, I will describe some important advances in our understanding of solid state/condensed matter systems. Notably, topological aspects have come to the fore in recent years and we now have a number of experimental examples of different types of topological phases. I will describe these and explain what distinguishes them from "ordinary" phases of matter. I will conclude with some theoretical advances our group has made in this area, summarize the main open questions in the field, and give some examples of new device applications that may arise from these intriguing states of matter.

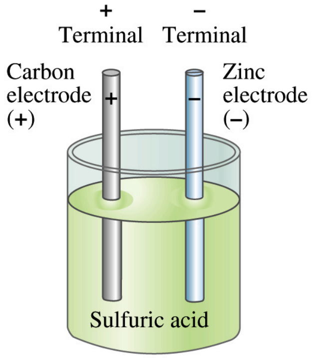
Refreshments will be served at 3:30p.m in the Physics Library

Electric Current and Resistance

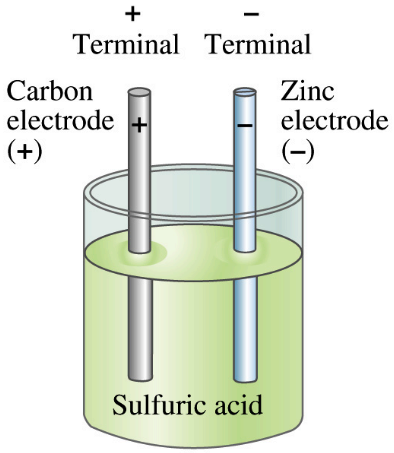
- So far we have been studying static electricity
  - What the heck is the static electricity?
    - The charges so far has not been moving but staying put at the location they are placed.
- Now we will learn dynamics of electricity
- What is the electric current?
  - A flow of electric charge
  - A few examples of the things that use electric current in everyday lives?
- In an electrostatic situation, there is no electric field inside a conductor but when there is current, there is field inside a conductor
  - Electric field is needed to keep charges moving

The Electric Battery

- What is a battery?
  - A device that produces electrical energy from the stored chemical energy and produces electricity.
- Electric battery was invented by Volta in 1790s in Italy
  - It was made of disks of zinc and silver based on his research that certain combinations of materials produce a greater electromotive force (emf), or potential, than others
- Simplest batteries contain two plates made of dissimilar metals, electrodes
  - Electrodes are immersed in a solution, electrolyte
  - This unit is called a cell and many of these form a battery
- Zinc and Iron in the figure are the terminals



How does a battery work?



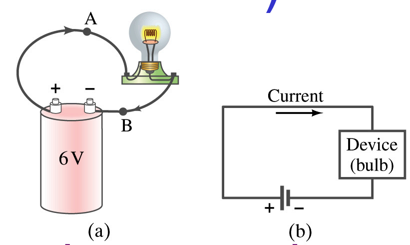
- One of the electrodes in the figure is zinc and the other carbon
- The acid electrolyte reacts with the zinc electrode and dissolves it.
- Each zinc atom leaves two electrons in the electrode and enters into the solution as a positive ion ➔ zinc electrode acquires negative charge and electrolyte becomes positively charged and pulls off electrons from carbon, getting neutralized
- Thus the carbon electrode become positively charged
- Since the two terminals are oppositely charged, there is potential difference between them

How does a battery work, cnt'd?

- When the terminals are not connected, only small amount of zinc is dissolved into the solution.
- How is a particular potential maintained?
  - If the terminals are not connected, as large number of zinc ion get produced,
  - zinc electrode gets increasingly charged up negative
  - zinc ions get recombined with the electrons in zinc electrode
- Why does battery go dead?
  - When the terminals are connected, the negative charges will flow away from the zinc electrode
  - More zinc atoms dissolve into the electrolyte to produce more charge
  - One or more electrode get used up not producing any more charge.

Electric Current

- When a circuit is powered by a battery (or a source of emf) the charge can flow through the circuit.



- Electric Current: Any flow of charge
  - Current can flow whenever there is potential difference between the ends of a conductor (or when the two ends have opposite charges)
    - The current can flow even through the empty space
  - Electric current in a wire can be defined as the net amount of charge that passes through the wire's full cross section at any point per unit time (just like the flow of water through a conduit…)
  - Average current is defined as: $\overline{I} = \Delta Q / \Delta t$
  - The instantaneous current is: $I = dQ/dt$
  - What kind of a quantity is the current? Scalar

Unit of the current?

C/s

1A=1C/s

In a single circuit, conservation of electric charge guarantees that the current at one point of the circuit is the same as any other points on the circuit.

Example 25 – 1

Current is flow of charge: A steady current of 2.5A flows in a wire for 4.0min. (a) How much charge has passed by any point in the circuit? (b) How many electrons would this be?

Current is total amount charge flow through a circuit in a given time. So from $\Delta Q = I\Delta t$ we obtain

$$\Delta Q = I\Delta t = 2.5 \times 4.0 \times 60 = 600C$$

The total number of electrons passed through the circuit is

$$N_e = \frac{\Delta Q}{e} = \frac{600C}{1.6 \times 10^{-19} C} = 3.8 \times 10^{21} electrons$$

Direction of the Electric Current

- What do conductors have in abundance?
  - Free electrons
- What happens if a continuous loop of conducting wire is connected to the terminals of a battery?
  - Electrons start flowing through the wire continuously as soon as both the terminals are connected to the wire. How?
    - The potential difference between the battery terminals sets up an electric field inside the wire and in the direction parallel to it
    - Free electrons in the conducting wire get attracted to the positive terminal
    - The electrons leaving negative terminal flow through the wire and arrive at the positive terminal
      - Electrons flow from negative to positive terminal
  - Due to historical convention, the direction of the current is opposite to the direction of flow of electrons ➔ Conventional Current

Ohm's Law: Resistance and Resistors

- What do we need to produce electric current?
  - Potential difference
- Georg S. Ohm experimentally established that the current is proportional to the potential difference ($I \propto V$)
  - If we connect a wire to a 12V battery, the current flowing through the wire is twice that of 6V, three times that of 4V and four times that of 3V battery.
  - What happens if we reverse the sign of the voltage?
    - It changes the direction of the current flow.
    - Does not change the magnitude of the current.
  - Just as in water flow cases, if the height difference is large the flow rate is large ➔ If the potential difference is large, the current is large.

Ohm's Law: Resistance

- The exact amount of current flow in a wire depends on
  - The voltage
  - The resistance of the wire to the flow of electrons
    - Just like the gunk in water pipe slows down water flow
    - Electrons are slowed down due to interactions with the atoms of the wire
- The higher the resistance the less the current for the given potential difference V
  - So how would you define resistance?
    - So that current is inversely proportional to the resistance

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

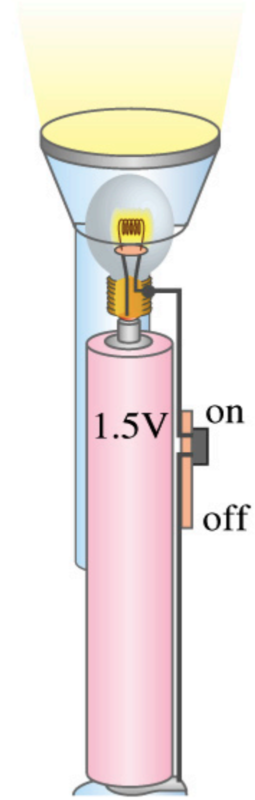
Unit? ohms Ω

$\boxed{1.0\Omega = 1.0V / A}$

  - Often this is rewritten as $\boxed{V = IR}$ Ohm's Law
  - The metal conductor's resistance R is a constant independent of V.
  - When the current I passes through resistance R, the voltage drop V occurs.
  - This linear relationship is not valid for some materials like diodes, vacuum tubes, transistors etc. ➔ These are called non-ohmic

Example 25 – 4

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



From Ohm's law, we obtain

$$R = \frac{V}{I} = \frac{1.5V}{300mA} = \frac{1.5V}{0.3A} = 5.0\Omega$$

Would the current increase or decrease, if the voltage reduces to 1.2V?

If the resistance did not change, the current is

$$I = \frac{V}{R} = \frac{1.2V}{5.0\Omega} = 0.24A = 240mA$$

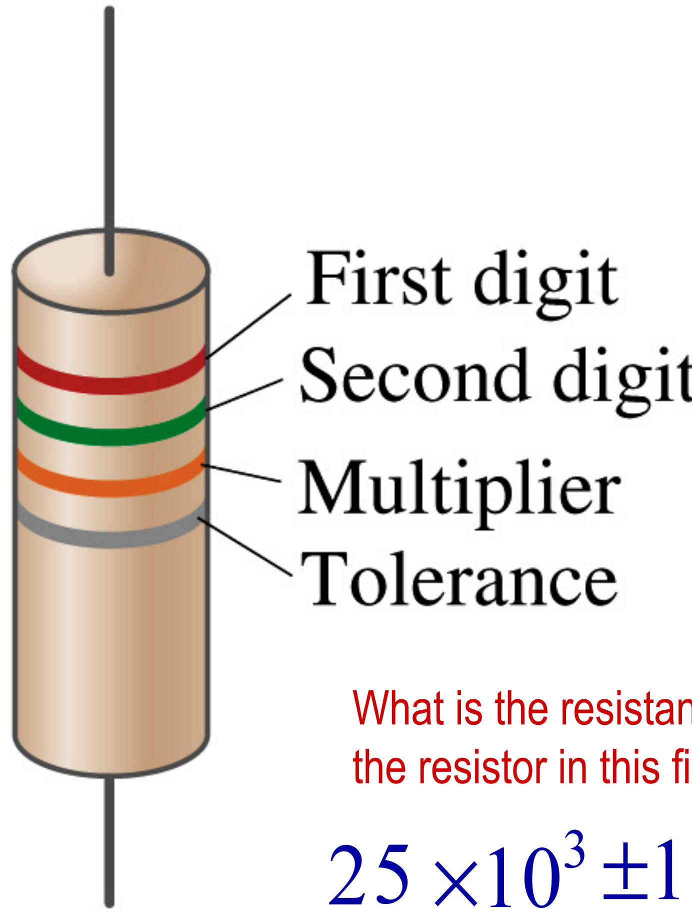
Ohm's Law: Resistors

- All electric devices provide 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 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 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	+/-1%
Red	2	10^2	+/-2%
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	+/-0.5%
Blue	6	10^6	+/-0.25%
Violet	7	10^7	+/-0.1%
Gray	8	10^8	+/-0.05%
White	9	10^9	
Gold		10^{-1}	5%
Silver		10^{-2}	10%
None			20%

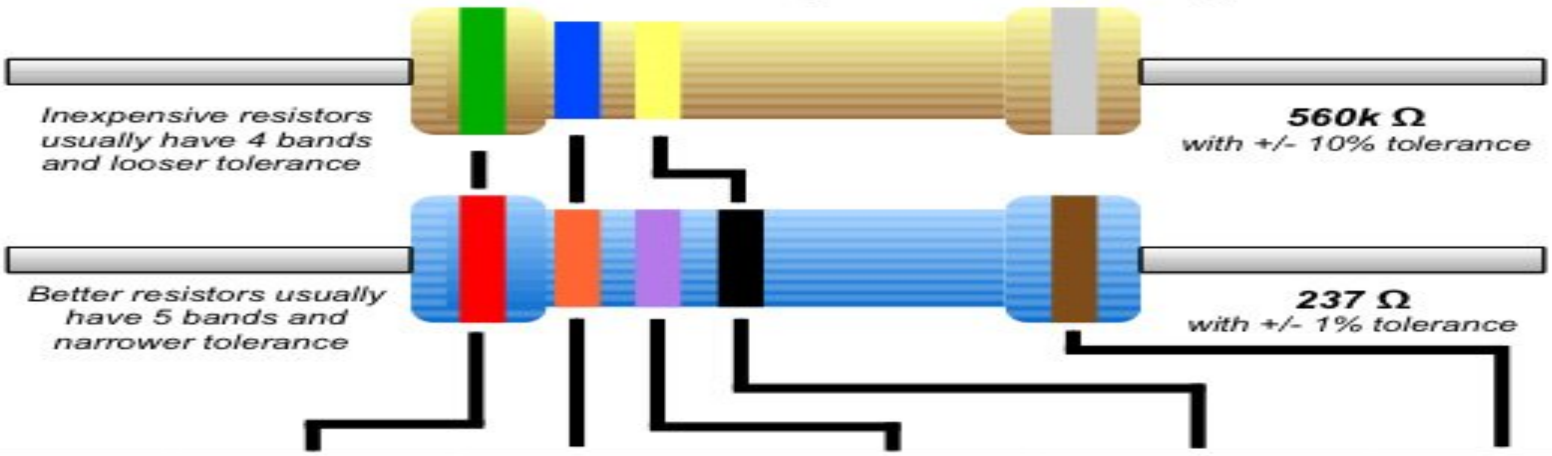


What is the resistance of the resistor in this figure?

$$25\times10^{3}\pm10\%\ \boxed{\Omega}$$

Resistor Identification

The end with more bands should point left when reading colors.



Color	1st Band	2nd Band	3rd Band	Multiplier	Tolerance
Black	0	0	0	x 1 Ω	
Brown	1	1	1	x 10 Ω	+/- 1%
Red	2	2	2	x 100 Ω	+/- 2%
Orange	3	3	3	x 1K Ω	
Yellow	4	4	4	x 10K Ω	
Green	5	5	5	x 100K Ω	+/- .5%
Blue	6	6	6	x 1M Ω	+/- .25%
Violet	7	7	7	x 10M Ω	+/- .1%
Grey	8	8	8		+/- .05%
White	9	9	9		
Gold				x .1 Ω	+/- 5%
Silver				x .01 Ω	+/- 10%

Surface-Mount

Surface-Mount (SMD) resistors use a similar system. Resistance is indicated by a 3-digit code like 104, sometimes followed by a letter. Rare, precision resistors have 4 digits (3+multiplier).

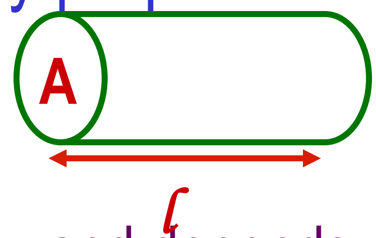
1st Digit	2nd Digit	3rd Digit (rare)	Multiplier
1	0		4

(10 with 4 zeros)
= **100k Ω**

- 0 Ω resistors (marked “0”) are used instead of wire links to simplify robotic assembly.
- Resistors less than 100Ω use a 0 multiplier to mean “x 1” so “100” = 10Ω, “470” = 47Ω

Resistivity

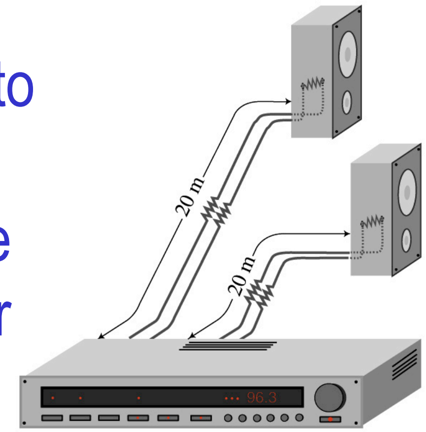
- It is experimentally found that the resistance R of a metal wire is directly proportional to its length ℓ and inversely proportional to its cross-sectional area A



  - How would you formularize this? $\boxed{R = \rho \frac{l}{A}}$
  - 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 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 **conductivity**, σ, $\boxed{\sigma = \frac{1}{\rho}}$

Example 25 – 5

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 $\rho_{Cu} = 1.68 \times 10^{-8} \Omega \cdot m$ **Table 25.1**

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

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

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

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

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

Example 25 – 6

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 $R = \rho \dfrac{l}{A}$

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

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?
  - Because 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

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

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