PHYS 1444 – Section 501
Lecture #9

Wednesday, Feb. 15, 2006
Dr. Jaehoon Yu

- Molecular description of Dielectric Material
- Electric Current and Resistance
- The Battery
- Electric Current and Its Direction
- Ohm's Law

Today's homework is #5, due 7pm, Thursday, Mar. 2!!

Announcements

- ## Quiz results
  - Class average: 45/70 ➔ 64/100
  - Want to know how you did in quiz1?
    - Average: 45/60 ➔ 75/100
  - Top score: 70
- ## 1st term exam next Wednesday, Feb. 22
  - Covers CH21 – what we finish today (25 – 3?)
  - For your exam preparation, we will NOT have a class next Monday, Feb. 20
- ## Reading assignments
  - CH24 – 6 and CH 25 – 1

Effect of a Dielectric Material

- Let's consider the two cases below:

Case #1 : constant V

$$V_0 \quad +Q_0 \quad C_0 = \frac{Q_0}{V_0} \longrightarrow V_0 \quad +Q_0 = +KQ_0 \quad C = \frac{Q}{V_0} = KC_0$$
$$-Q_0 \qquad\qquad -Q_0 = -KQ_0$$

no dielectric → with dielectric

(a) Voltage constant

Case #2 : constant Q

$$V_0 \quad +Q_0 \quad C_0 = \frac{Q_0}{V_0} \longrightarrow +Q_0 \quad V_0, \; C_0 = \frac{Q_0}{V_0} \longrightarrow +Q_0 \quad V = \frac{V_0}{K}$$
$$-Q_0 \qquad\qquad -Q_0 \qquad\qquad\qquad -Q_0 \quad C = KC_0$$

no dielectric → battery disconnected → dielectric inserted

(b) Charge constant

- Constant voltage: Experimentally observed that the total charge on the each plate of the capacitor increases by K as the dielectric material is inserted between the gap ➜ $Q=KQ_0$
  - The capacitance increased to $C=Q/V_0=KQ_0/V_0=KC_0$

- Constant charge: Voltage found to drop by a factor K ➜ $V=V_0/K$
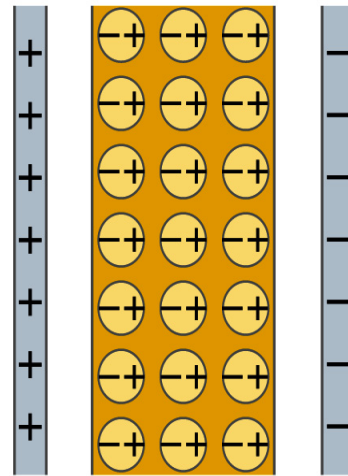 - The capacitance increased to $C=Q_0/V=KQ_0/V_0=KC_0$

Molecular Description of Dielectric

- So what in the world makes dielectrics behave the way they do?

- We need to examine this in a microscopic scale.

- Let's consider a parallel plate capacitor that is charged up $+Q(=C_0 V_0)$ and $-Q$ with air in between.

  - Assume there there is no way any charge can flow in or out

$+Q$ $-Q$
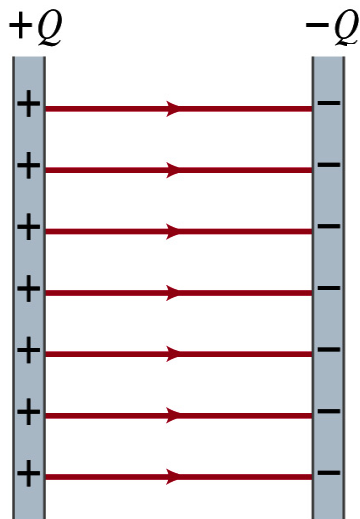
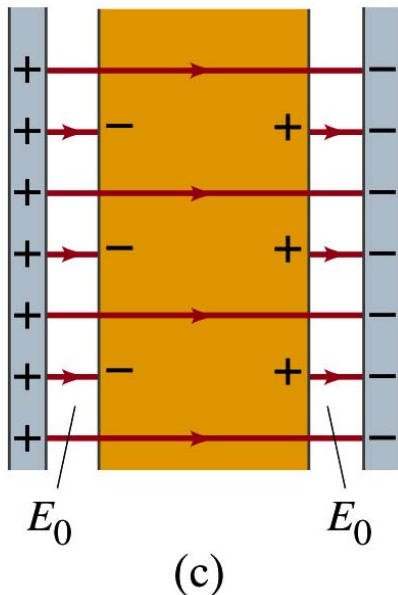- Now insert a dielectric

  - Dielectrics can be polar ➔ could have permanent dipole moment. What will happen?

- Due to the electric field molecules may be aligned.

(a)   (b)

Molecular Description of Dielectric

- OK. Then what happens?

- Then effectively, there will be some negative charges close to the surface of the positive plate and positive charges close to the negative plate

  - Some electric field do not pass through the whole dielectric but stops at the negative charge

  - So the field inside dielectric is smaller than the air

- Since electric field is smaller, the force is smaller

  - The work need to move a test charge inside the dielectric is smaller

  - Thus the potential difference across the dielectric is smaller than across the air

E_0 E_0

(c)

Electric Current and Resistance

- So far we have been studying static electricity
  - What 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 called terminals

+
Terminal   Terminal

Carbon
electrode
(+)

Zinc
electrode
(−)

Sulfuric acid
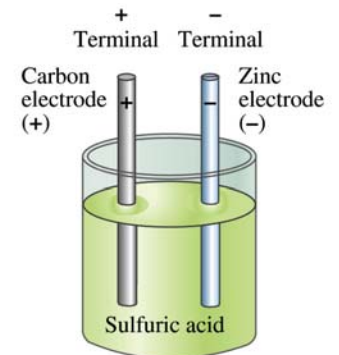
How does a battery work?

- 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 the electrolyte becomes positively charged

- The carbon electrode picks up the positive charge

- Since the two terminals are oppositely charged, there is potential difference between them
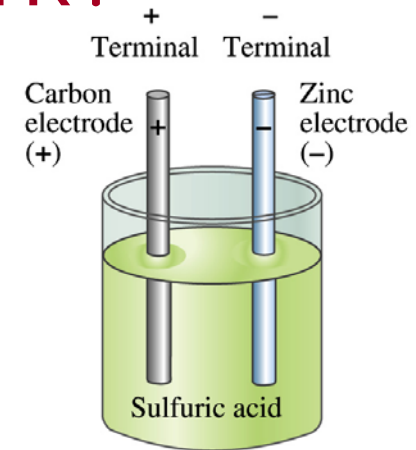
How does a battery work?

- When the terminals are not connected, only the necessary amount of zinc is dissolved into the solution.

- How is a particular potential maintained?
  - As too many of zinc ion gets produced, if the terminals are not connected,
    - 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: $\bar{I} = \Delta Q/\Delta t$

  - The instantaneous current is: $I = dQ/dt$

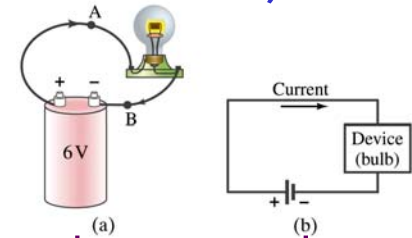 - What kind of a quantity is the current? Scalar

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 the flow of charge: A steady current of 2.5A flows in a wire for 4.0min. (a) How much charge 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 case, 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 $R = \dfrac{V}{I}$ Unit? ohms Ω
  - Often it is rewritten as $V = IR$ Ohm's Law
  - What does this mean?
    $$1.0\Omega = 1.0V / A$$
    - The metal conductor's resistance R is a constant independent of V.
  - This linear relationship is not valid for some materials like diodes, vacuum tubes, transistors etc. ➔ These are called non-ohmic

Example 25 – 3

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

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