PHYS 1444 – Section 02
Lecture #9

Tuesday Sep. 25, 2012
Dr. Andrew Brandt

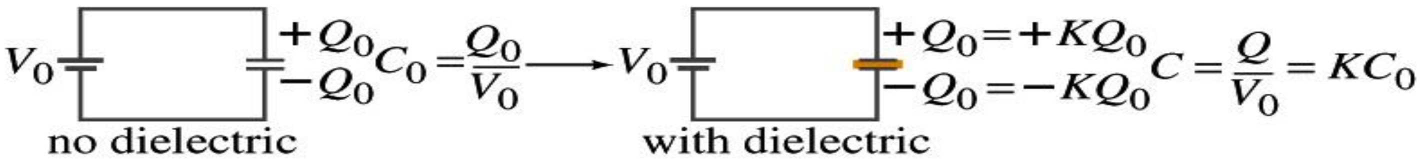
- Chapter 24
  - Dielectrics
- Chapter 25
  - Electric Current
  - Resistance
  - The Battery
  - Ohm's Law: Resistors
  - Resistivity
  - Electric Power

HW Ch 23-24 due today
HW5 Ch 25 will be due Tues. Oct. 2
Review will be on Oct. 2 in class
***Test 1 will be Thurs Oct 4 ch 21-25**

Effect of a Dielectric Material

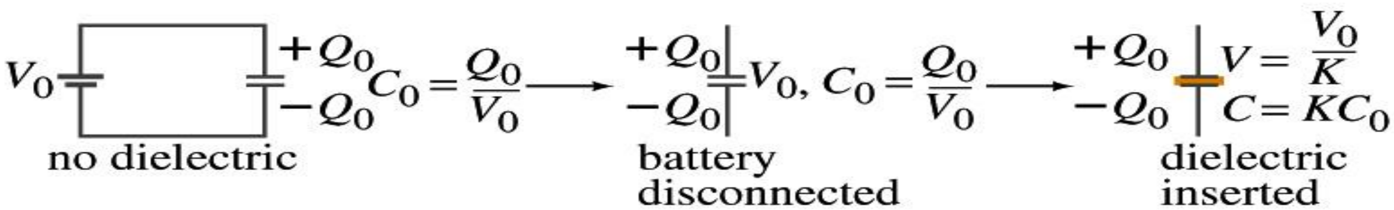
- Let's consider the two cases below:

Case #1 : constant V



(a) Voltage constant

Case #2 : constant Q

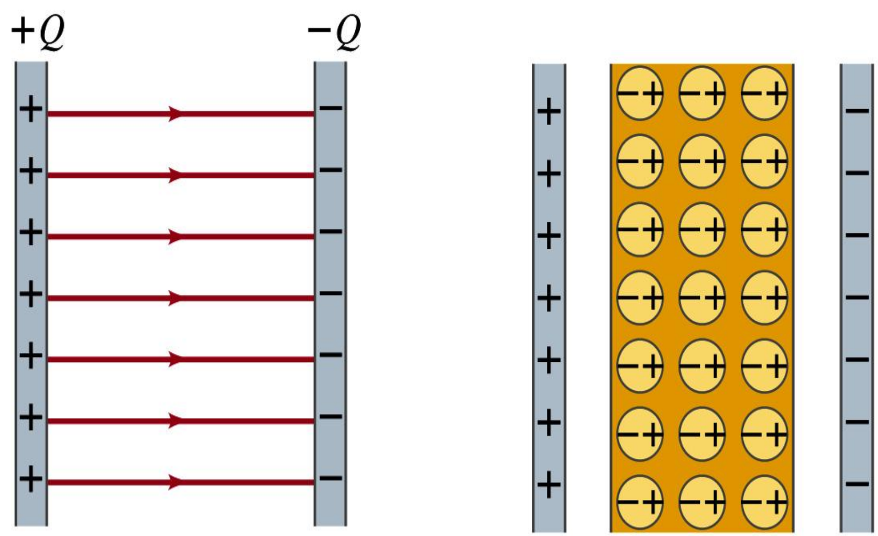


(b) Charge constant

- Constant voltage: Experimentally observed that the total charge on 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 makes dielectrics behave the way they do?
- We need to examine this on a microscopic scale.
- Let's consider a parallel plate capacitor that is charged up $+Q(=C_0V_0)$ and –Q with air in between.
  - Assume that charge cannot flow in or out

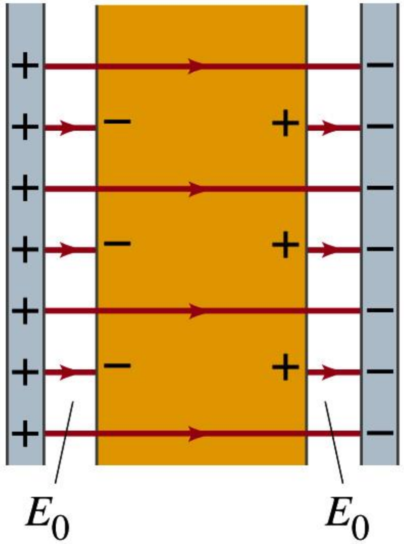


(a) (b)

- Now insert a dielectric
  - Dielectrics can be polar ➔ may have a permanent dipole moment.
  - Due to the electric field molecules may be aligned.

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 does not pass through the whole dielectric but stops at the negative charge

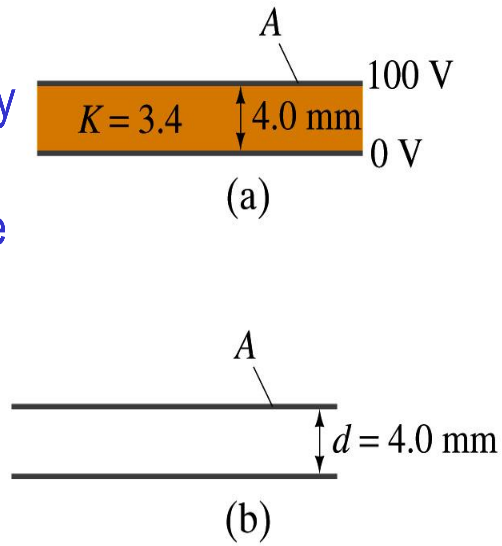


(c)

  - 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

Example 24 – 8

Dielectric Removal: A parallel-plate capacitor, filled with a dielectric with K=3.4, is connected to a 100-V battery. After the capacitor is fully charged, the battery is disconnected. The plates have area $A=4.0m^2$, and are separated by d=4.0mm. (a) Find the capacitance, the charge on the capacitor, the electric field strength, and the energy stored in the capacitor. (b) The dielectric is carefully removed, without changing the plate separation nor does any charge leave the capacitor. Find the new value of capacitance, electric field strength, voltage between the plates and the energy stored in the capacitor.



(a) $$C = \frac{\varepsilon A}{d} = \frac{K\varepsilon_0 A}{d} = 3.4 \times 8.85 \times 10^{-12}\, C^2/N \cdot m^2 \; \frac{4.0m^2}{4.0 \times 10^{-3}\, m} = 3.0 \times 10^{-8}\, F = 30nF$$

$$Q = CV = 3.0 \times 10^{-8}\, F \; \times 100V = 3.0 \times 10^{-6}\, C = 3.0\mu C$$

$$E = \frac{V}{d} = \frac{100V}{4.0 \times 10^{-3}\, m} = 2.5 \times 10^{4}\, V/m$$

$$U = \frac{1}{2} CV^2 = \frac{1}{2} \; 3.0 \times 10^{-8}\, F \;\; 100V \;^2 = 1.5 \times 10^{-4}\, J$$

Example 24 – 8 cont'd

(b) Since the dielectric has been removed, the effect of dielectric constant must be removed as well.

$$C_0 = \frac{C}{K} = 8.85\times10^{-12}\,C^2/N\cdot m^2\;\frac{4.0m^2}{4.0\times10^{-3}m} = 8.8\times10^{-9}F = 8.8nF$$

Since the charge is the same ($Q_0 = Q$) before and after the removal of the dielectric, we obtain

$$V_0 = Q/C_0 = K\,Q/C = KV = 3.4\times100V = 340V$$

$$E_0 = \frac{V_0}{d} = \frac{340V}{4.0\times10^{-3}m} = 8.5\times10^4\,V/m = 84\,kV/m$$

$$U_0 = \frac{1}{2}C_0V_0^2 = \frac{1}{2}\frac{C}{K}\left(KV\right)^2 = \frac{1}{2}KCV^2 = KU = 3.4\times1.5\times10^{-4}J = 5.1\times10^{-4}J$$

Where did the extra energy come from?

~~T[illegible] of energy conservation is violated per[illegible]?~~

Wrong!
Wrong!
Wrong!

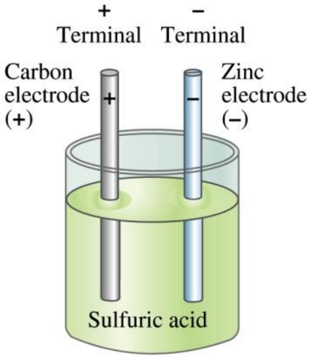
External force has done work of 3.6×10^{-4}J on the system to remove dielectric!!

Electric Current and Resistance

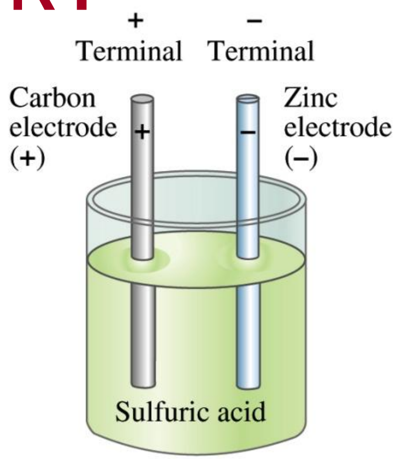
- So far we have been studying electrostatics:
  - The charges have been at rest
- Now we will learn electrodynamics
  - Charges in motion
- What is the electric current?
  - A flow of electric charge
  - Examples of things that use electric current?
- In an electrostatic situation, there is no electric field inside a conductor but when there is current, there **is** a 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



How does a battery work?



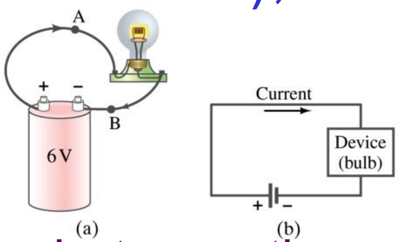
- One of the electrodes in the figure is zinc and the other carbon
- The acid electrolyte reacts with the zinc electrode and dissolves it.
- Each zinc atom leaves two electrons on the electrode and enters into the solution as a positive ion → the zinc electrode acquires negative charge and the electrolyte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

How does a battery work?

- When the terminals are not connected, a certain amount of zinc is dissolved into the solution establishing an equilibrium condition.
- How is a particular equilibrium potential maintained?
  - If the terminals are not connected:
    - the zinc electrode becomes negatively charged up to the equilibrium pint
    - zinc ions then recombine with the electrons in the 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 electrodes get used up stopping the flow of charge

Electric Current

- When a circuit is powered by a battery (or a source of emf), 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)
  - 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 pipe)
  - 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 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 point 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 continuously through the wire 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 the case of water flow through a pipe, 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 diameter and composition of a 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
  - Often it is rewritten as $V = IR$ Ohm's Law
  - What does this mean?
    - 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

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

Unit?

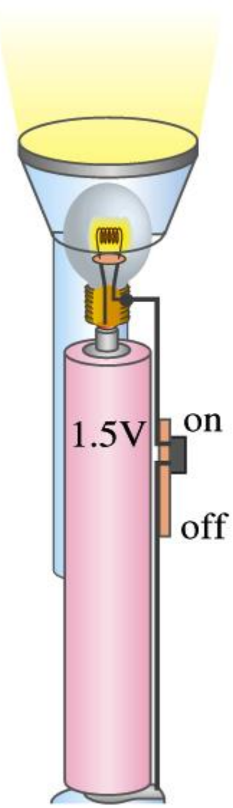
ohms

Ω

$1.0\Omega = 1.0V/A$

Example 25 – 3

Flashlight bulb resistance: A small flashlight bulb draws 300 mA 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

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

That would be a decrease!