PHYS 1441 – Section 002
Lecture #11

Wednesday, Oct. 10, 2018

Dr. Jaehoon Yu

- Chapter 24 Capacitance etc..
  - Effect of Dielectric
  - Molecular description of Dielectric Material
- Chapter 25
  - Electric Current and Resistance
  - The Battery
  - Ohm's Law: Resisters, Resistivity

Announcements

- Reminder: Mid Term Exam
  - In class Wednesday, Oct. 17
  - Covers CH21.1 through what we cover in class Monday, Oct. 15 + appendix
  - Bring your calculator but DO NOT input formula into it!
    - Cell phones or any types of computers cannot replace a calculator!
  - BYOF: You may bring a one 8.5x11.5 sheet (front and back) of **handwritten** formulae and values of constants
  - No derivations, word definitions or solutions of any kind!
  - No additional formulae or values of constants will be provided!
- Mid-term grade discussions
  - From 12:00 – 2:30pm, Wednesday, Oct. 24 in my office (CPB342)
  - Last name starts with A – D (12 – 12:30), E– K (12:30 – 1), L – O (1 – 1:30), P – S (1:30 – 2:00), T – Z (2-2:30)
- Colloquium at 4pm today in SH100
  - Dr. G. Glass, UNT

Physic Department
The University of Texas at Arlington
<u>COLLOQUIUM</u>

High Energy Focused Ion Beams - Technology and Applications

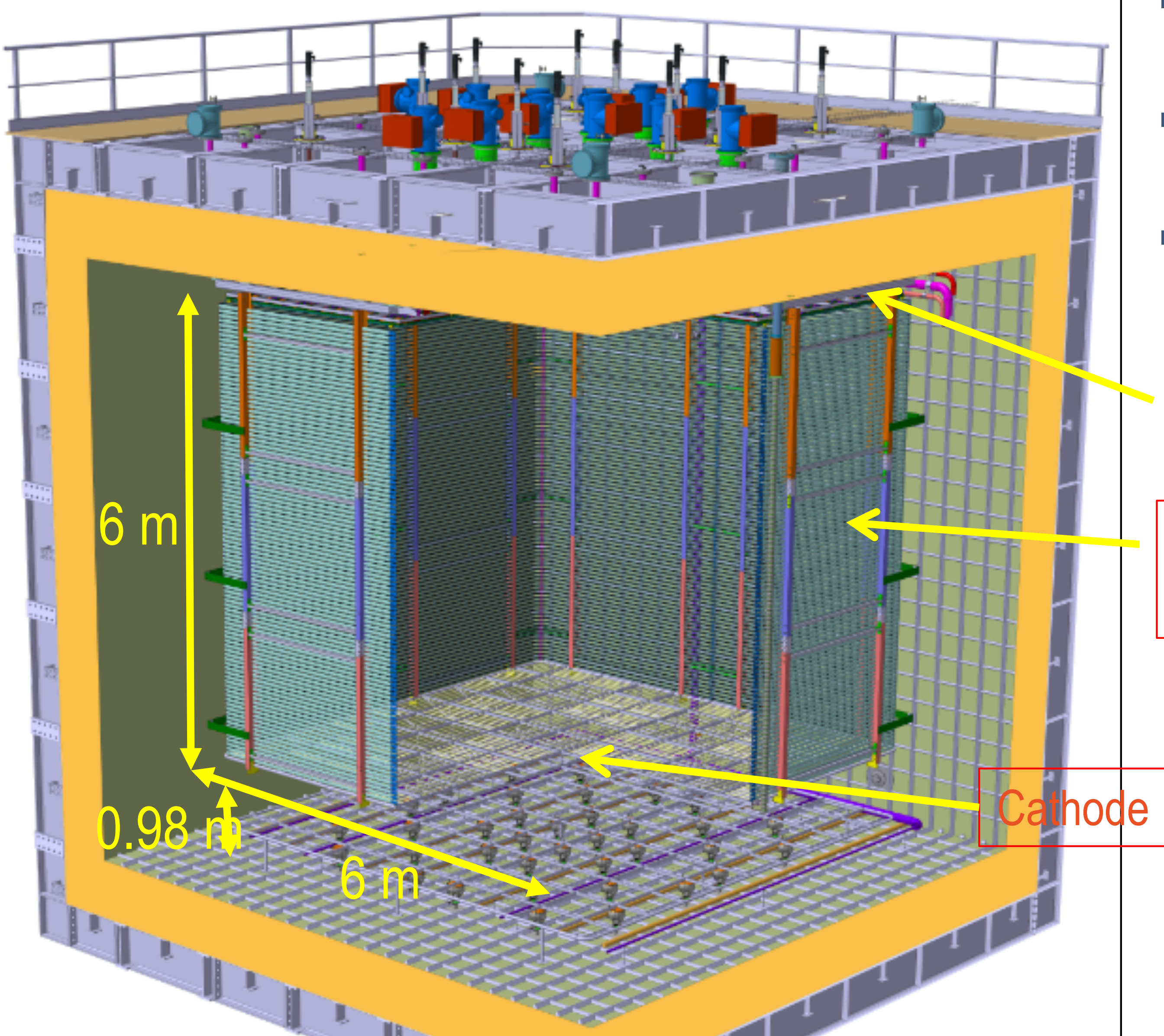
Gary A. Glass
University of North Texas

Wednesday October 10, 2018
4:00 p.m. Room 100 Science Hall

Abstract
There is an ongoing critical need for new-generation techniques to probe materials structure and properties with nanoscale resolutions and to manipulate organic and inorganic nano-materials. High energy (MeV) ions can penetrate well below surfaces of materials with negligible scattering and with precisely controllable ion-atom interactions, thereby offering a unique means by which surface to sub-surface regions can be studied and/or manipulated. Typically, magnetic focusing systems have been utilized worldwide as the mainstay of MeV proton microprobe systems and these systems have attained notable operational accomplishments. But the inability of these systems to focus heavy ion beams has skewed virtually all work with focused MeV ion beams to those topics for which proton beams can be used – the remainder of the periodic table had remained essentially untouched. Recently, however, technological advances have allowed the development of electrostatic microprobe focusing systems, thereby opening new avenues for applications. This presentation will provide an overview of MeV ion focusing systems and describe a few development and applications of these systems at the Ion Beam Modification and Analysis Laboratory of the University of North Texas.

Refreshments will be served in the physics lounge at 3:30

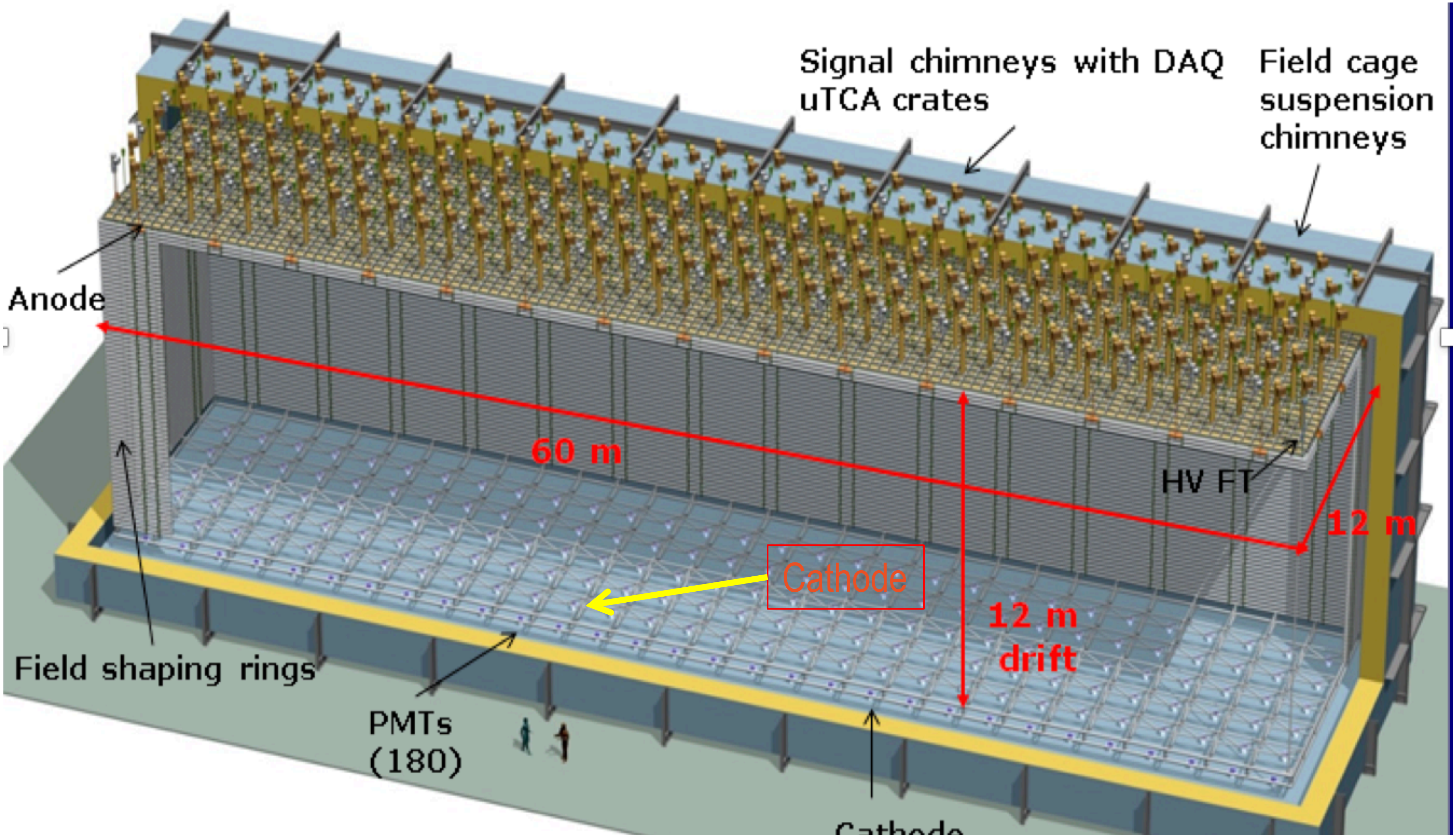
ProtoDUNE Dual Phase



- Field Cage and cathode hangs off of the ceiling
- Essential to have light yet sturdy structure
- Based on modular concept as SP

What is the stored energy in between ProtoDUNE cathode (-300kV) plate (6mx6m) and the cryostat wall (0V), d=98cm, LAr K=1.6?

DUNE Dual Phase

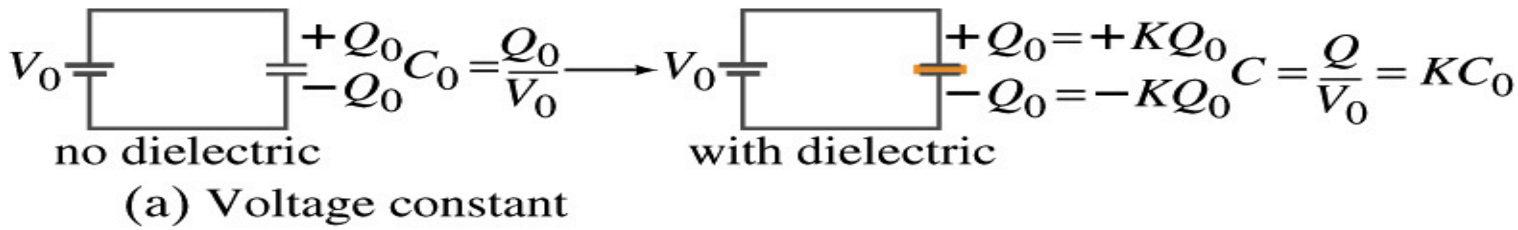


What are the stored energies in between DUNE cathode (-750kV) plate (12mx60m) and the cryostat wall (0V) and in between 3mx3m unit plate and the ground, d=98cm, LAr K=1.6?

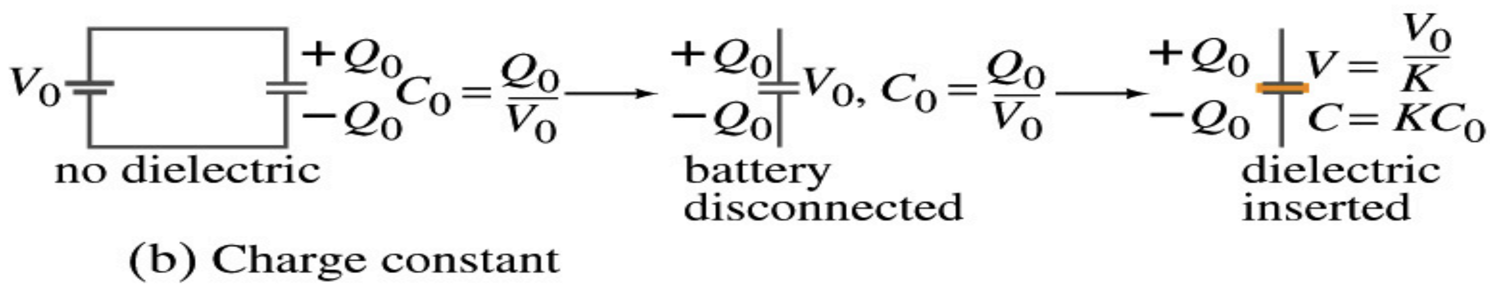
Effect of a Dielectric Material on Capacitance

- Let's consider the two cases below:

Case #1 : constant V



Case #2 : constant Q



- Constant voltage: Experimentally observed that the total charge on each plate of the capacitor increases by K as a dielectric material is inserted between the gap ➔ $Q=KQ_0$
  - The capacitance increased to $C=Q/V_0=KQ_0/V_0=KC_0$ ➔ $Q=CV_0=KC_0V_0=KQ_0$
- Constant charge: Voltage found to drop by a factor K ➔ $V=V_0/K$
  - The capacitance increased to $C=Q_0/V=KQ_0/V_0=KC_0$ ➔ $V=Q_0/C=Q_0/(KC_0)=V_0/K$

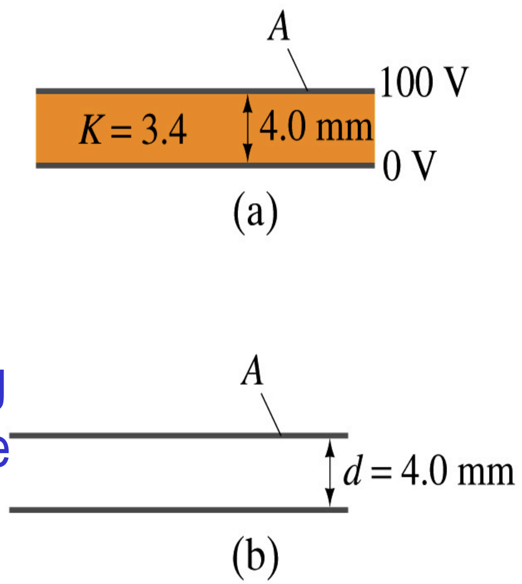
Effect of a Dielectric Material on Field

- What happens to the electric field within a dielectric?
- Without a dielectric, the field is $$E_0 = \frac{V_0}{d}$$
  - What are V_0 and d?
    - V_0: Potential difference between the two plates w/o dielectric
    - d: separation between the two plates
- For the constant voltage, the electric field remains the same
- For the constant charge: the voltage drops to $V=V_0/K$, thus the field in the dielectric is $$E = E_D = \frac{V}{d} = \frac{V_0}{dK} = \frac{E_0}{K}$$
  - The field in the dielectric is reduced.

$$E_D = \frac{E_0}{K}$$

Example 24 – 11

Dielectric Removal: A parallel-plate capacitor, filled with the dielectric of 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) $$C=\frac{\varepsilon A}{d}=\frac{K\varepsilon_0 A}{d}=\left(3.4\times 8.85\times 10^{-12}\, C^2/N\cdot m^2\right)\frac{4.0m^2}{4.0\times 10^{-3}\, m}=3.0\times 10^{-8}\, F=30nF$$

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

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

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

Example 24 – 11 cont'd

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

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

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

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

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

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

Where did the extra energy come from?

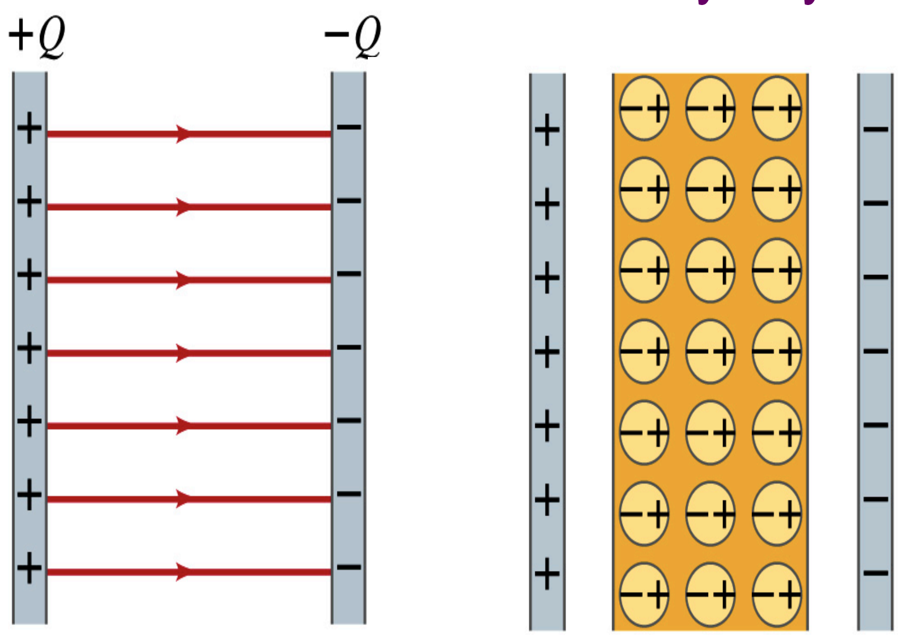
~~Th ... ergy conservation law is violated in elec ... ??~~

Wrong!
Wrong!
Wrong!

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

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 $+Q(=C_0V_0)$ and $-Q$ with air in between.
  - Assume there is no way any charge can flow in or out

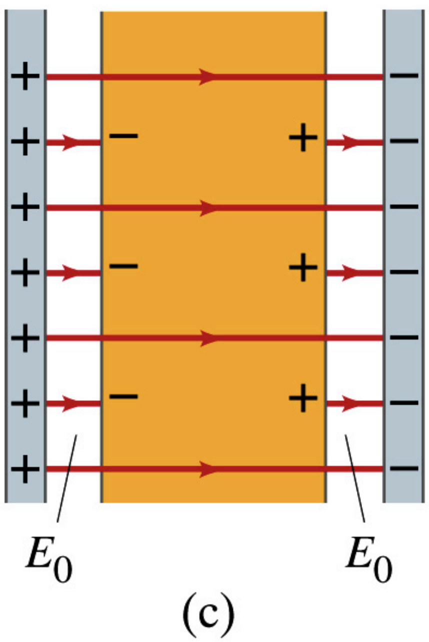


(a) (b)

- Now insert a dielectric
  - Dielectric can be polar ➔ could have permanent dipole moment. What will happen?
- Due to the electric field molecules will 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 charge on the negative plate
  - Some electric field do not pass through the whole dielectric but stops at the negative charge



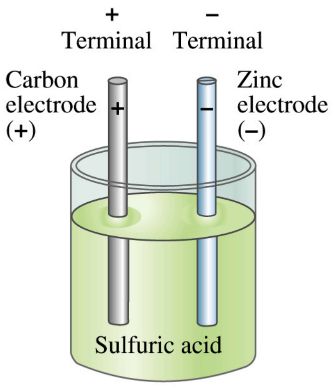
  - So the field inside dielectric is smaller than the air
- Since electric field is smaller, the force is smaller
  - The work need to move a test charge inside the dielectric is smaller
  - Thus the potential difference across the dielectric is smaller than across the air

Electric Current and Resistance

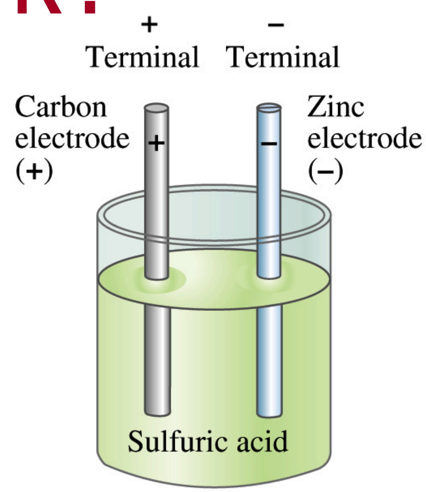
- So far we have been studying static electricity
  - What is the static electricity?
    - The charges so far have not been moving but staying put at the location they are placed.
- Now we will learn dynamics of electricity
- What is the electric current?
  - A flow of electric charge
  - A few examples 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. Why?
  - 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 ➔ Maintains potential difference!
- 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 called electrodes
  - Electrodes are immersed in a solution, the electrolyte
  - This unit is called a cell and many of these form a battery
- Zinc and Carbon in the figure are called terminals



How does a battery work?



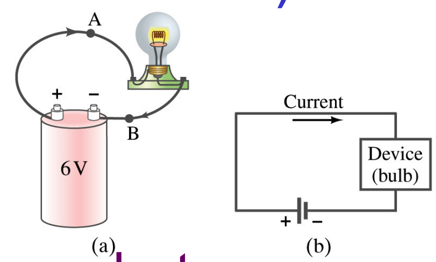
- One of the electrodes in the figure is zinc and the other carbon
- The acid electrolyte reacts with the zinc electrode and dissolves it.
- Each zinc atom leaves two electrons in the electrode and enters into the solution as a positive ion ➔ zinc electrode acquires negative charge and the electrolyte (the solution) 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, only the necessary amount of zinc is dissolved into the solution.
- How is a particular potential maintained?
  - If the terminals are not connected, as too many of zinc ion gets 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 a 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 under certain conditions
  - 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: $\boxed{\bar{I} = \Delta Q / \Delta t}$
  - The instantaneous current is: $\boxed{I = dQ / dt}$
  - What kind of a quantity is the current?

Unit of the current?

C/s

1A=1C/s

Scalar

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 a 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 flown 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

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

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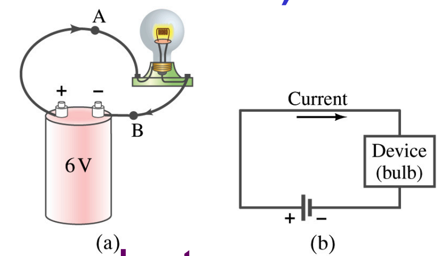

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Direction of the Electric Current

- 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

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

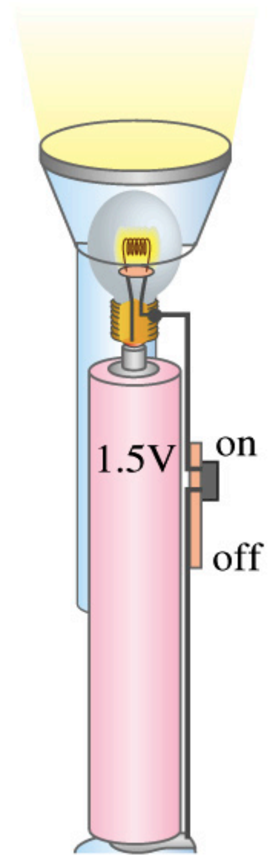
Unit? ohms Ω

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

  - Often it is rewritten as $\boxed{V = IR}$ 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

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

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