PHYS 1441 – Section 002
Lecture #10

Monday, Oct. 8, 2018

Dr. Jaehoon Yu

- Chapter 24 Capacitance etc..
  - Capacitors in Series or Parallel
  - Electric Energy Storage
  - Effect of Dielectric
  - Molecular description of Dielectric Material
- Chapter 25
  - Electric Current and Resistance

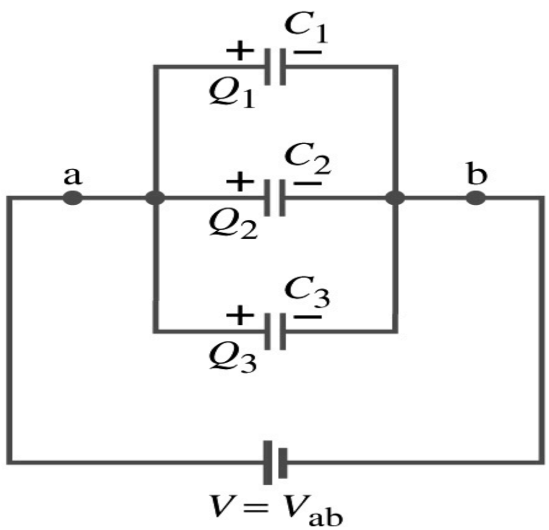
Today's homework is #7, due 11pm, Monday, Oct. 15!!

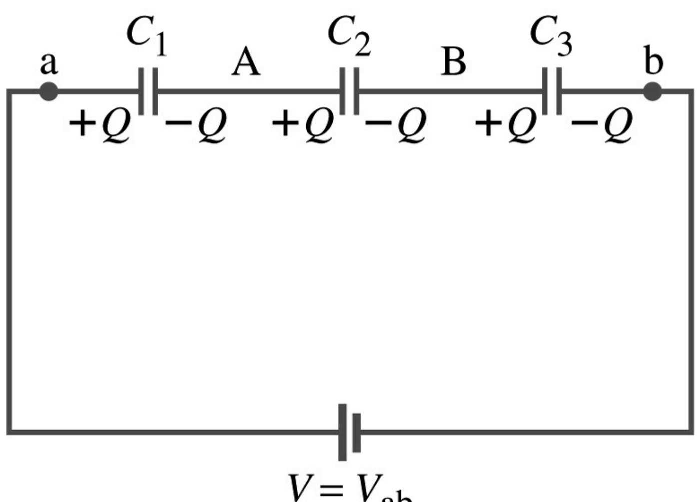
Announcements

- Quiz 2 results
  - Class average: 33/60
    - Equivalent to 55/100
    - Previous quiz: 74/100
  - Top score: 62/60
- 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!

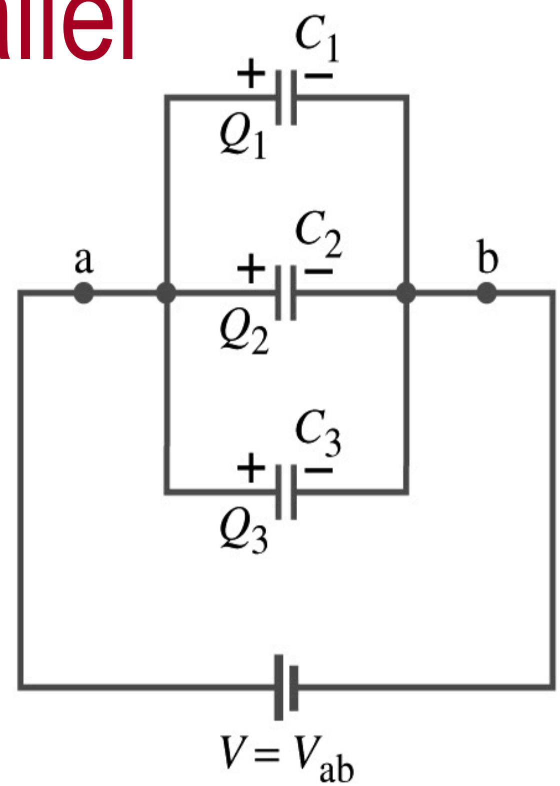
Capacitors in Series or Parallel

- Capacitors may be used in electric circuits
- What is an electric circuit?
  - A closed path of conductors, usually wires connecting capacitors and other electrical devices, in which
    - Charges can flow
    - And includes a voltage source such as a battery
- Capacitors can be connected in various ways.
  - In parallel, in series or in combination





Capacitors in Parallel

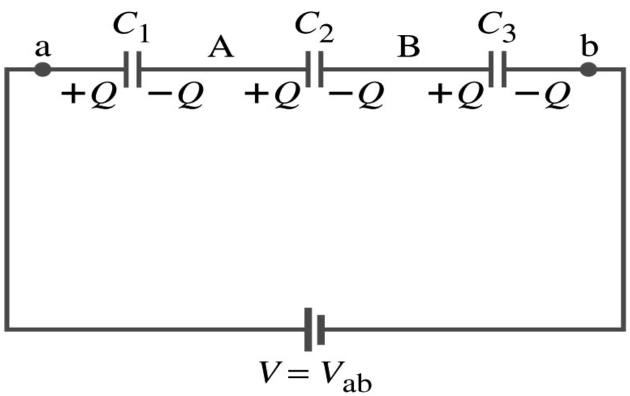


- Parallel arrangement provides the **same voltage** across all the capacitors.
  - Left hand plates are at V_a and right hand plates are at V_b
  - So each capacitor plate acquires charges given by the formula
    - $Q_1=C_1V$, $Q_2=C_2V$, and $Q_3=C_3V$
- The total charge Q that must leave the battery is then
  - $Q=Q_1+Q_2+Q_3=V(C_1+C_2+C_3)$
- Consider that the three capacitors behave like an equivalent one
  - $Q=C_{eq}V= V(C_1+C_2+C_3)$
- Thus the equivalent capacitance in parallel is $C_{eq} = C_1 + C_2 + C_3$

What is the net effect?

The capacitance increases!!!

Capacitors in Series



- Series arrangement is more interesting
  - When battery is connected, +Q flows to the left plate of C_1 and –Q flows to the right plate of C_3.
  - Since capacitors in between were originally neutral, charges get induced to neutralize the ones in the middle.
  - So the charge on each capacitor plate is the same value, Q. (**Same charge**)
- Consider that the three capacitors behave like an equivalent one
  - $Q=C_{eq}V$
- The total voltage V across the system of three capacitors in series must be equal to the sum of the voltages across each capacitor.
  - $V=V_1+V_2+V_3=Q/C_1+Q/C_2+Q/C_3$
- Putting all these together, we obtain:
- $V=Q/C_{eq}=Q(1/C_1+1/C_2+1/C_3)$
- Thus the equivalent capacitance is

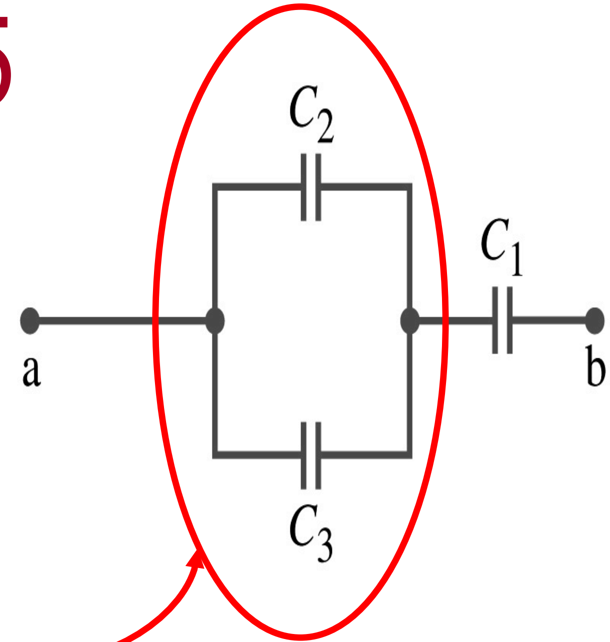
$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

What is the net effect?

The capacitance smaller than the smallest C!!!

Example 24 – 5

Equivalent Capacitor: Determine the capacitance of a single capacitor that will have the same effect as the combination shown in the figure. Take $C_1=C_2=C_3=C$.



We should do these first!!

How? These are in parallel so the equivalent capacitance is:

$$C_{eq1} = C_1 + C_2 = 2C$$

Now the equivalent capacitor is in series with C1.

$$\frac{1}{C_{eq}} = \frac{1}{C_{eq1}} + \frac{1}{C_2} = \frac{1}{2C} + \frac{1}{C} = \frac{3}{2C}$$

Solve for C_{eq}

$$C_{eq} = \frac{2C}{3}$$

Electric Energy Storage

- A charged capacitor stores energy.
  - The stored energy is the amount of the work done to charge it.
- The net effect of charging a capacitor is removing one type of charge from one plate and put them on to the other.
  - Battery does this when it is connected to a capacitor.
- Capacitors do not get charged immediately.
  - Initially when the capacitor is uncharged, no work is necessary to move the first bit of charge. Why?
    - Since there is no charge, there is no field that the external work needs to overcome.
  - When some charge is on each plate, it requires work to add more charges of the same sign due to the electric repulsion.

Electric Energy Storage

- The work needed to add a small amount of charge, dq, when a potential difference across the plate is V is: dW=Vdq.
- Since V=q/C, the work needed to store total charge Q is

$$W = \int_0^Q V\,dq = \frac{1}{C}\int_0^Q q\,dq = \frac{Q^2}{2C}$$

- Thus, the energy stored in a capacitor when the capacitor carries the charges +Q and –Q on each plate is

$$U = \frac{Q^2}{2C}$$

- Since Q=CV, we can rewrite

$$U = \frac{Q^2}{2C} = \frac{1}{2}CV^2 = \frac{1}{2}QV$$

Example 24 – 8

Energy store in a capacitor: A camera flash unit stores energy in a 150μF capacitor at 200V. How much electric energy can be stored?

Using the formula for stored energy. Umm.. Which one?

What do we know from the problem? C and V

So we use the one with C and V: $U = \frac{1}{2}CV^2$

$$U = \frac{1}{2}CV^2 = \frac{1}{2}\left(150 \times 10^{-6}F\right)\left(200V\right)^2 = 3.0J$$

How do we get J from FV²? $FV^2 = \left(\frac{C}{V}\right)V^2 = CV = C\left(\frac{J}{C}\right) = J$

Electric Energy Density

- The energy stored in a capacitor can be considered as being stored in the electric field between the two plates
- For a uniform field E between two plates, V=Ed and $C=\varepsilon_0 A/d$
- Thus the stored energy is

$$U = \frac{1}{2}CV^2 = \frac{1}{2}\left(\frac{\varepsilon_0 A}{d}\right)(Ed)^2 = \frac{1}{2}\varepsilon_0 E^2 Ad$$

- Since Ad is the gap volume V, we can obtain the energy density, stored energy per unit volume, as

$$u = \frac{1}{2}\varepsilon_0 E^2$$

Valid for any space that is vacuum

Electric energy stored per unit volume in any region of space is proportional to the square of E in that region.

Dielectrics

- Capacitors have an insulating sheet of material, called dielectric, between the plates to
  - Increase breakdown voltage greater than that in air (3MV/m)
  - Apply higher voltage to the gap without the charge passing across
  - Allow the plates get closer together without touching
    - Increases capacitance (recall $C=\varepsilon_0 A/d$)
  - Increase the capacitance by the dielectric constant

$$C = KC_0$$

  - Where C_0 is the intrinsic capacitance when the gap is vacuum

Dielectrics

- The value of dielectric constant K varies depending on the material (Table 24 – 1)
  - K for vacuum is 1.0000
  - K for air is 1.0006 (this is why permittivity of air and vacuum are used interchangeably.)
  - K for paper is 3.7
- **Maximum electric field before breakdown** occurs is called the **dielectric strength**. What is its unit?
  - V/m
- The capacitance of a parallel plate capacitor with a dielectric (K) filling the gap is

$$C = KC_0 = K\varepsilon_0 \frac{A}{d}$$

Dielectrics

- A new quantity of the **permittivity of a dielectric material** is defined as **$\varepsilon = K\varepsilon_0$**
- The capacitance of a parallel plate capacitor with a dielectric medium filling the gap is

$$C = \varepsilon \frac{A}{d}$$

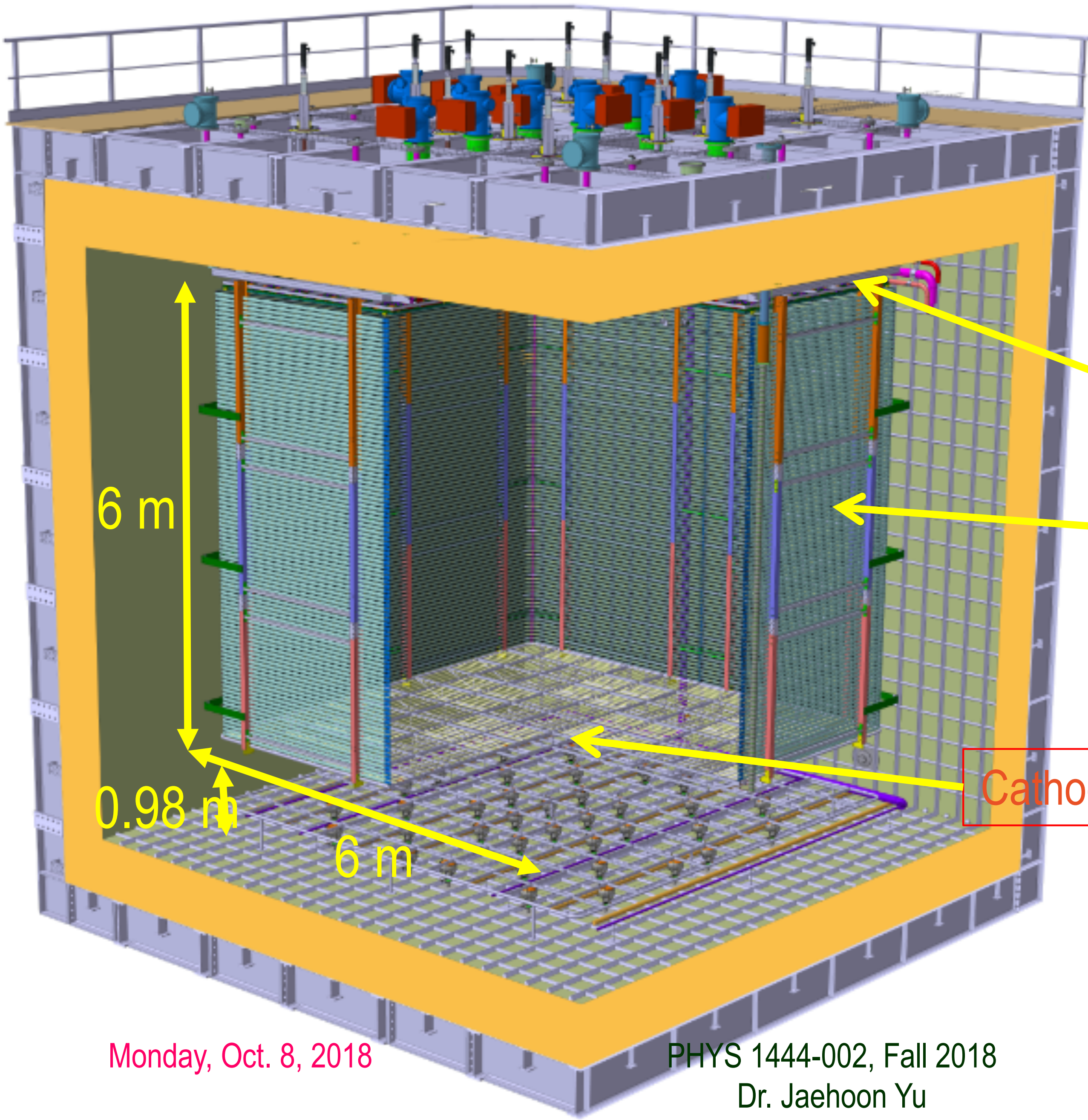
- The energy density stored in an electric field E in a dielectric is

$$u = \frac{1}{2} K \varepsilon_0 E^2 = \frac{1}{2} \varepsilon E^2$$

Valid for any space w/ dielectric whose permittivity ε.

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

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

DUNE Dual Phase