PHYS 1444 – Section 002
Lecture #11

Monday, Oct. 9, 2017

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
  - The Battery

Today's homework is #7, due 11pm, Monday, Oct. 16!!

Announcements

- Quiz 2 results
  - Class average: 27.7/60
    - Equivalent to 46.2/100
    - Previous quizzes: 48/100
  - Top score: 48/60
- Mid Term Exam
  - In class next Wednesday, Oct. 18
  - Covers CH21.1 through what we cover in class Monday, Oct. 16 + 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!
- Triple credit colloquium 3:30pm this Wednesday in NH100
  - Dr. Michael Turner of U. of Chicago, National Academy of Science member

The Department of Physics Colloquium Series presents

Λ-CDM: “Much more than we expected, but now less than what we want.”

3:30 p.m., Wednesday, October 11

Nedderman Hall, Room 100

A reception will follow the talk at 4:30 p.m. in the Nedderman Hall Atrium

Abstract:
The Λ-CDM (Lambda Cold Dark Matter) cosmological model is remarkable. With just six parameters it describes the evolution of the Universe from a very early time when all structures were quantum fluctuations on subatomic scales to the present, and it is consistent with a wealth of high-precision data, both laboratory measurements and astronomical observations. However, the foundation of Λ-CDM involves physics beyond the standard model of particle physics: particle dark matter, dark energy and cosmic inflation. Until this “new physics” is clarified, Λ-CDM is at best incomplete and at worst a phenomenological construct that accommodates the data. I discuss the path forward, which involves both discovery and disruption, some grand challenges and finally the limits of scientific cosmology.

Michael Turner, *Ph.D.*

Dr. Michael Turner is a theoretical cosmologist and is the Bruce V. & Diana M. Rauner Distinguished Service Professor at the University of Chicago. He is a member of the National Academy of Sciences and coined the term “dark energy” in 1998. He helped establish the interdisciplinary field that combines together cosmology and elementary particle physics to understand the origin and evolution of the Universe. Dr. Turner served as president of the American Physical Society in 2013 and from 2003-06 served as assistant director for the National Science Foundation’s Division of Mathematical and Physical Sciences. He has won numerous awards for his research, including the Helen B. Warner Prize from the American Astronomical Society. He received his Ph.D. in Physics from Stanford University in 1978.

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SCIENCE WEEK

OCTOBER 9-14, 2017

Example 24 – 1

Capacitor calculations: (a) Calculate the capacitance of a capacitor whose plates are 20cmx3.0cm and are separated by a 1.0mm air gap. (b) What is the charge on each plate if the capacitor is connected to a 12-V battery? (c) What is the electric field between the plates? (d) Estimate the area of the plates needed to achieve a capacitance of 1F, given the same air gap.

(a) Using the formula for a parallel plate capacitor, we obtain

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

$$= \left(8.85\times10^{-12}\ C^2/N\cdot m^2\right)\frac{0.2\times0.03m^2}{1\times10^{-3}\ m} = 53\times10^{-12}\ C^2/N\cdot m = 53pF$$

(b) From Q=CV, the charge on each plate is

$$Q = CV = \left(53\times10^{-12}\ C^2/N\cdot m\right)\left(12V\right) = 6.4\times10^{-10}C = 640pC$$

Example 24 – 1

(C) Using the formula for the electric field in two parallel plates

$$E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{A\varepsilon_0} = \frac{6.4\times10^{-10}\,C}{6.0\times10^{-3}\,m^2\times8.85\times10^{-12}\,C^2/N\cdot m^2} = 1.2\times10^4\,N/C = 1.2\times10^4\,V/m$$

Or, since $V = Ed$ we can obtain $E = \frac{V}{d} = \frac{12V}{1.0\times10^{-3}\,m} = 1.2\times10^4\,V/m$

(d) Solving the capacitance formula for A, we obtain

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

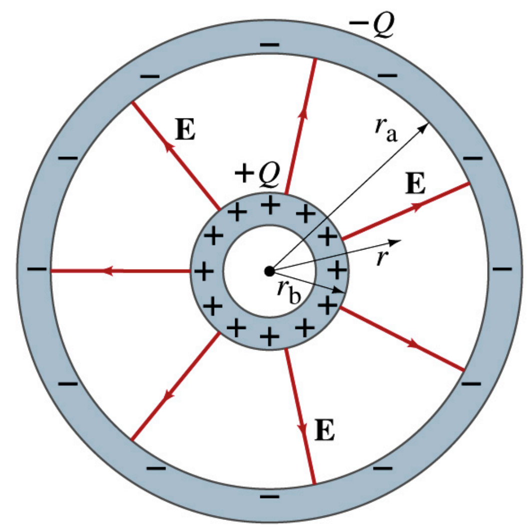
Solve for A

$$A = \frac{Cd}{\varepsilon_0} = \frac{1F\cdot1\times10^{-3}\,m}{\left(9\times10^{-12}\,C^2/N\cdot m^2\right)} \approx 10^8\,m^2 \approx 100km^2$$

About 40% the area of Arlington ($256km^2$).

Example 24 – 3

Spherical capacitor: A spherical capacitor consists of two thin concentric spherical conducting shells, of radius r_a and r_b, as in the figure. The inner shell carries a uniformly distributed charge Q on its surface and the outer shell an equal but opposite charge –Q. Determine the capacitance of the two shells.



Using Gauss' law, the electric field outside a uniformly charged conducting sphere is

$$E = \frac{Q}{4\pi\varepsilon_0 r^2}$$

So the potential difference between a and b is

$$V_{ba} = -\int_a^b \vec{E} \cdot d\vec{l} =$$

$$= -\int_a^b E \cdot dr = -\int_a^b \frac{Q}{4\pi\varepsilon_0 r^2} dr = -\frac{Q}{4\pi\varepsilon_0} \int_a^b \frac{dr}{r^2} = \frac{Q}{4\pi\varepsilon_0} \left(\frac{1}{r}\right)_{r_a}^{r_b} = \frac{Q}{4\pi\varepsilon_0} \left(\frac{1}{r_b} - \frac{1}{r_a}\right) = \frac{Q}{4\pi\varepsilon_0} \left(\frac{r_a - r_b}{r_b r_a}\right)$$

Thus capacitance is

$$C = \frac{Q}{V} = \frac{Q}{\frac{Q}{4\pi\varepsilon_0}\left(\frac{r_a - r_b}{r_b r_a}\right)} = \frac{4\pi\varepsilon_0 r_b r_a}{r_a - r_b}$$

Capacitor Cont'd

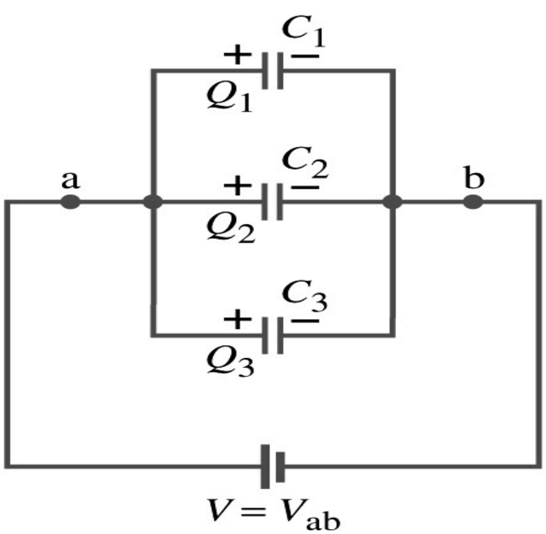
- A single isolated conductor can be said to have a capacitance, C.
- C can still be defined as the ratio of the charge to the absolute potential V on the conductor.
  - So Q=CV.
- The potential of a single conducting sphere of radius r_b can be obtained as

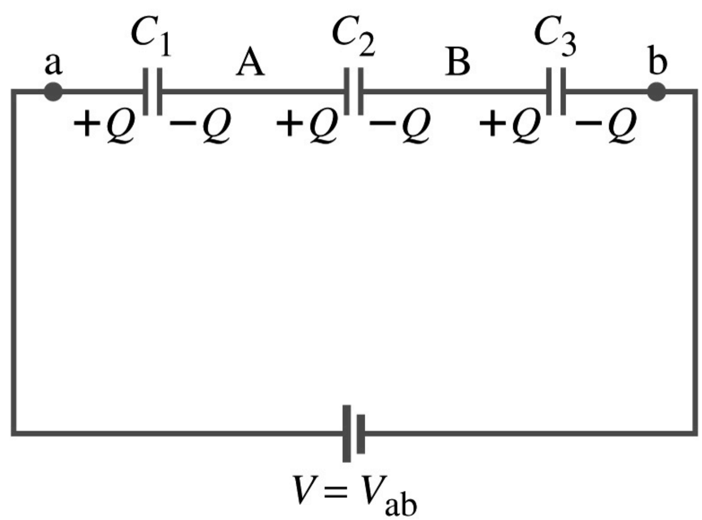
$$V = \frac{Q}{4\pi\varepsilon_0}\left(\frac{1}{r_b} - \frac{1}{r_a}\right) = \frac{Q}{4\pi\varepsilon_0 r_b} \qquad \text{where} \quad r_a \to \infty$$

- So its capacitance is $\boxed{C = \frac{Q}{V} = 4\pi\varepsilon_0 r_b}$

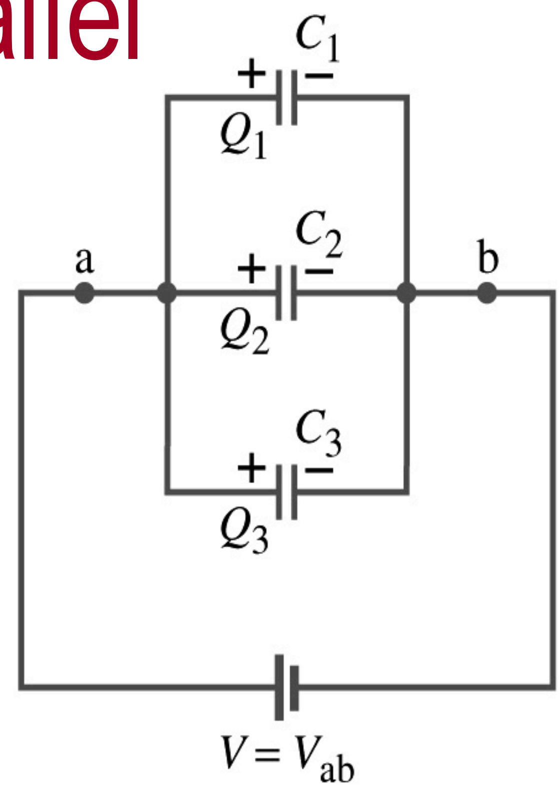
Capacitors in Series or Parallel

- 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

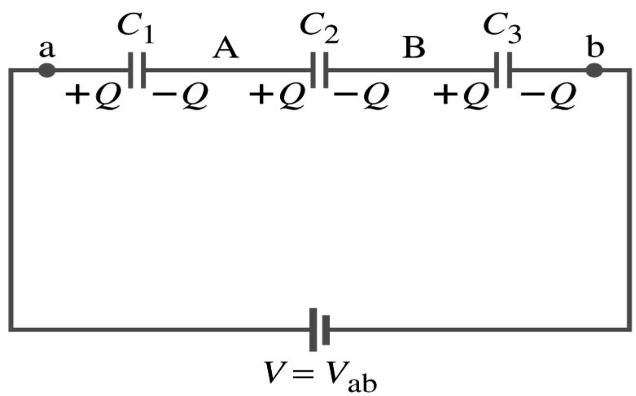


- Parallel arrangement provides the **<u>same voltage</u>** across all the capacitors.
  - Left hand plates are at V_a and right hand plates are at V_b
  - So each capacitor plate acquires charges given by the formula
    - $Q_1=C_1V$, $Q_2=C_2V$, and $Q_3=C_3V$
- The total charge Q that must leave the 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 $\boxed{C_{eq} = C_1 + C_2 + C_3}$

What is the net effect?

The capacitance increases!!!

Capacitors in Series



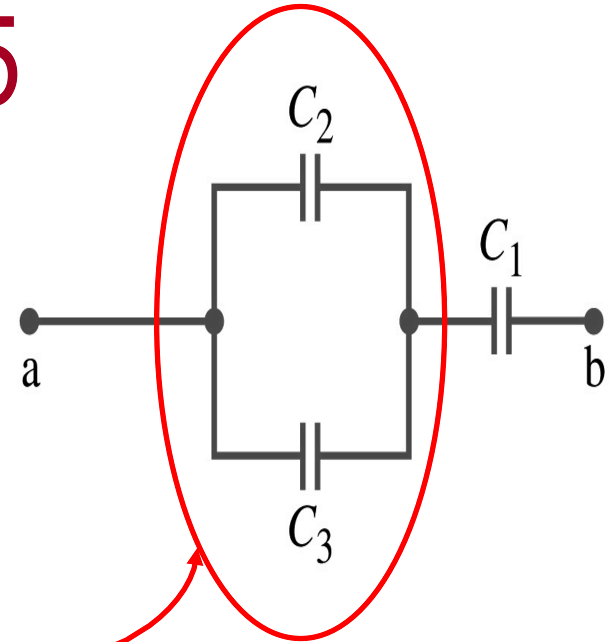
- Series arrangement is more interesting
  - When battery is connected, +Q flows to the left plate of C_1 and –Q flows to the right plate of C_3.
  - Since capatotors in between were originally neutral, charges get induced to neutralize the ones in the middle.
  - So the charge on each capacitor plate 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 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

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

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 charge 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: 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 is

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

- 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: $U = \frac{1}{2}CV^2$

$$U = \frac{1}{2}CV^2 = \frac{1}{2}\left(150\times10^{-6}F\right)\left(200V\right)^2 = 3.0J$$

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