PHYS 1444 – Section 002
Lecture 11

Wednesday, Oct. 2, 2019

Dr. Jaehoon Yu

CH 24

- Capacitors in Series or Parallel
- Electric Energy Storage
- Effect of Dielectric
- Molecular description of Dielectric Material

CH 25

- Electric Current and Resistance

Announcements

- Mid-term exam
  - Wednesday, Oct. 16 at the beginning of the class
  - Comprehensive exam which covers CH21.1 through what we cover in class Monday, Oct. 14 + the math refresher in A1 – A8
  - 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 for the quiz
  - No derivations, word definitions, set ups or solutions of any problems!
  - No additional formulae or values of constants will be provided!
- Reading assignment: CH24.6
- Colloquium today
  - Dr. A. Zimmermann of U.T. Austin

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PHYSICS DEPARTMENT

Colloquium:

Binary Black Holes and Gravitational Waves

Detections of gravitational waves have revealed an invisible side of the universe: black holes in binary systems. Observations of these systems test our understanding of black holes, their violent mergers, and the theory of general relativity. A combination of analytic approximations and numerical simulations is required to understand black hole binaries and predict the gravitational waves they emit. I will take us on a tour of these systems, describe the "ringdown" of the final merged black hole, and present the most recent results from the Advanced LIGO and Virgo detectors.

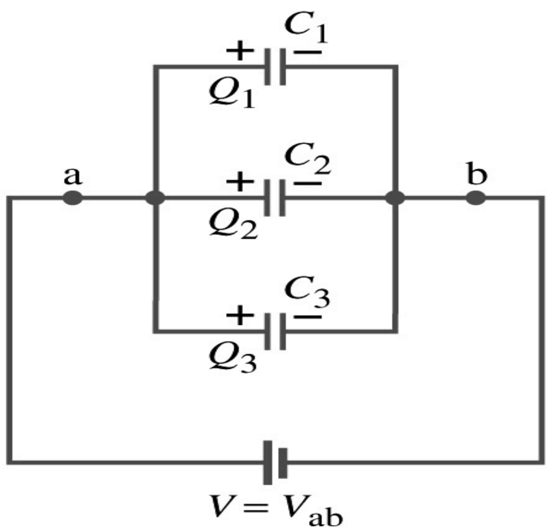
Aaron Zimmerman
The University of Texas at Austin

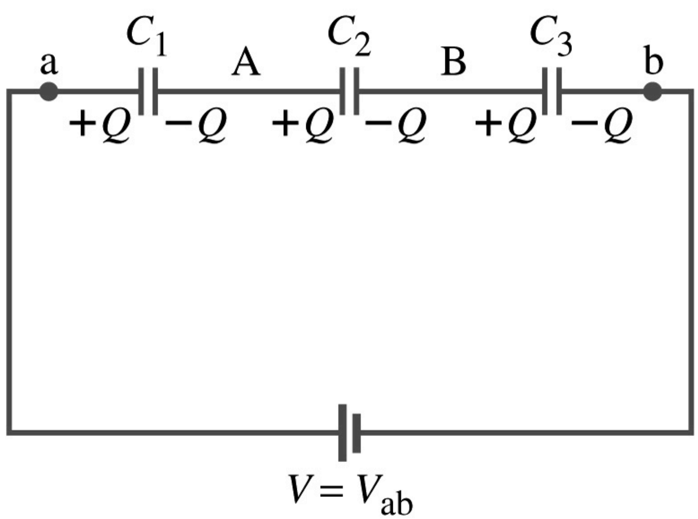
WEDNESDAY, OCTOBER 2
4PM ROOM 100 SCIENCE HALL
REFRESHMENTS AT 3:30PM IN 108 SCIENCE HALL

MAVERICK SCIENCE
UNIVERSITY OF TEXAS ARLINGTON
Innovate. Discover. Learn.

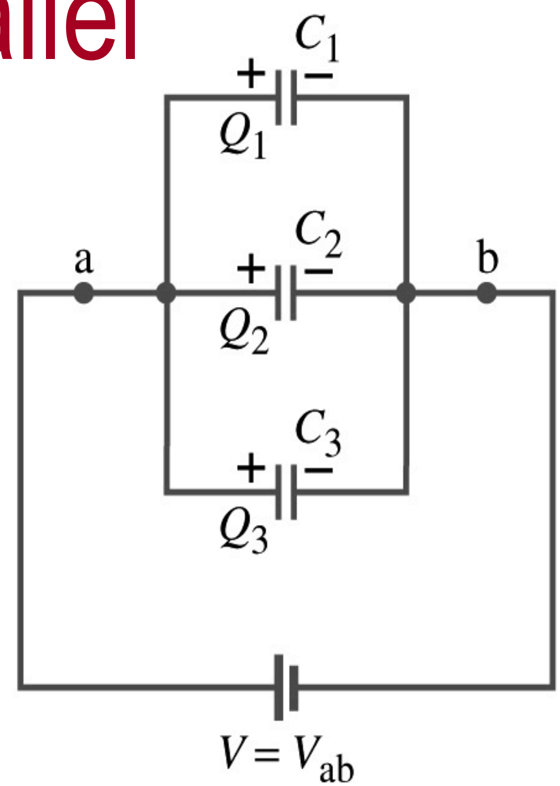
Capacitors in Series or Parallel

- 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

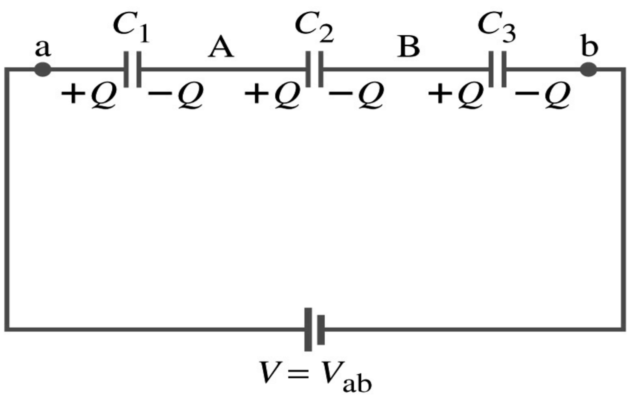


- Parallel arrangement provides the **same voltage** across all the capacitors.
  - Left hand plates are at V_a and the right hand plates are at V_b
  - So each capacitor plate acquires charges given by the formula
    - $Q_1=C_1V$, $Q_2=C_2V$, and $Q_3=C_3V$
- The total charge Q that must leave the 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 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 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

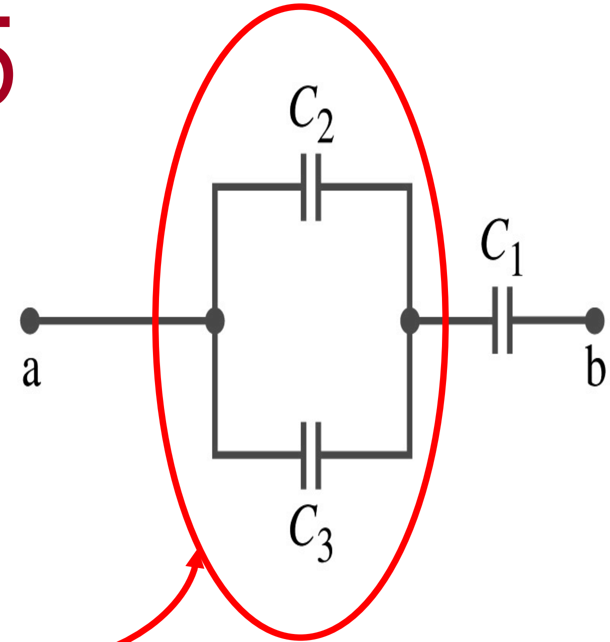
$$\boxed{\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

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 force needs to work 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: 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? $FV^2 = \left(\frac{C}{V}\right)V^2 = CV = C\left(\frac{J}{C}\right) = J$

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=ε_0A/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

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

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

$$\boxed{C = KC_0}$$

  - 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
- **The 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

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

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

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

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

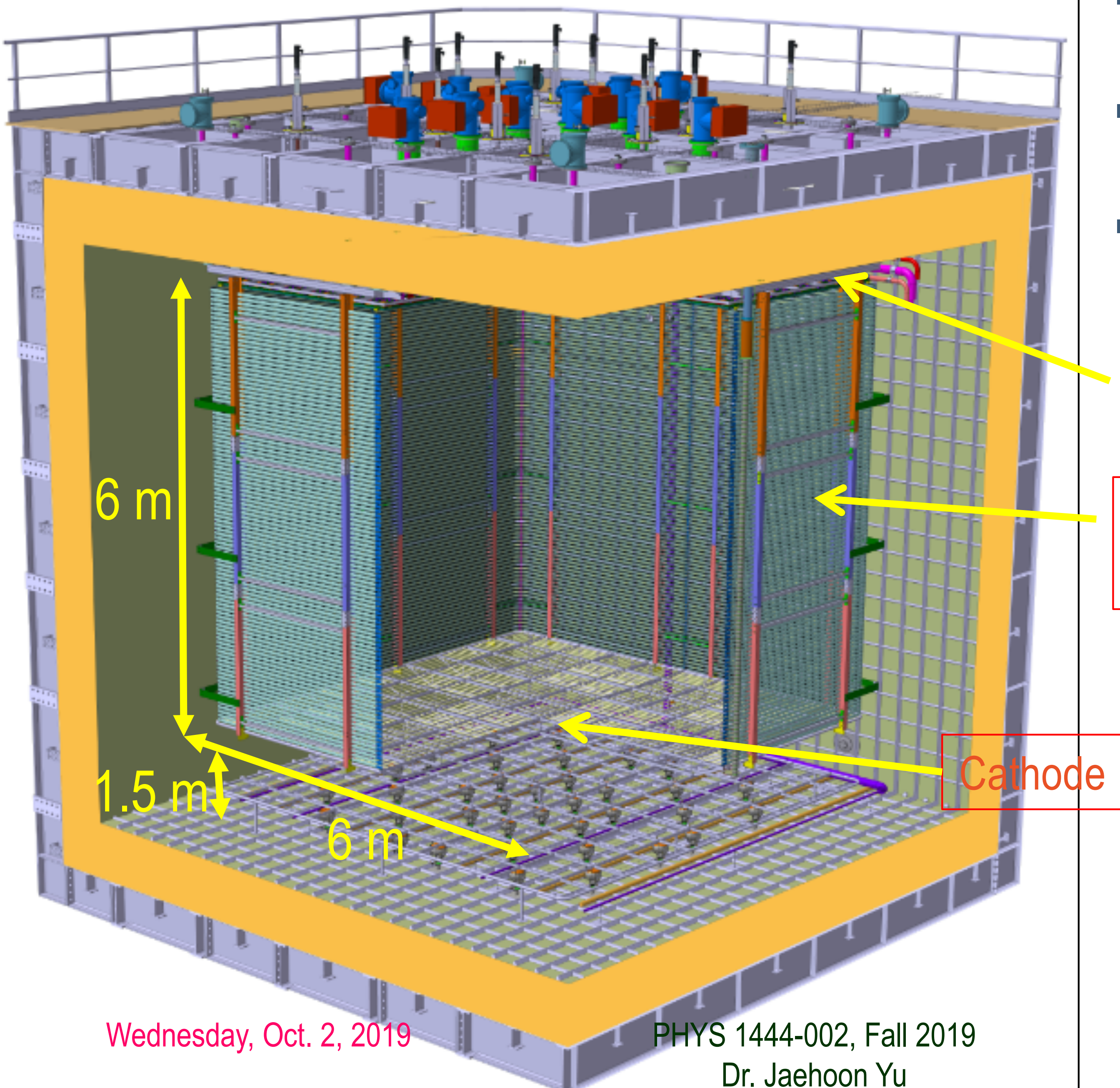
$$\boxed{u = \frac{1}{2} K \varepsilon_0 E^2 = \frac{1}{2} \varepsilon E^2}$$

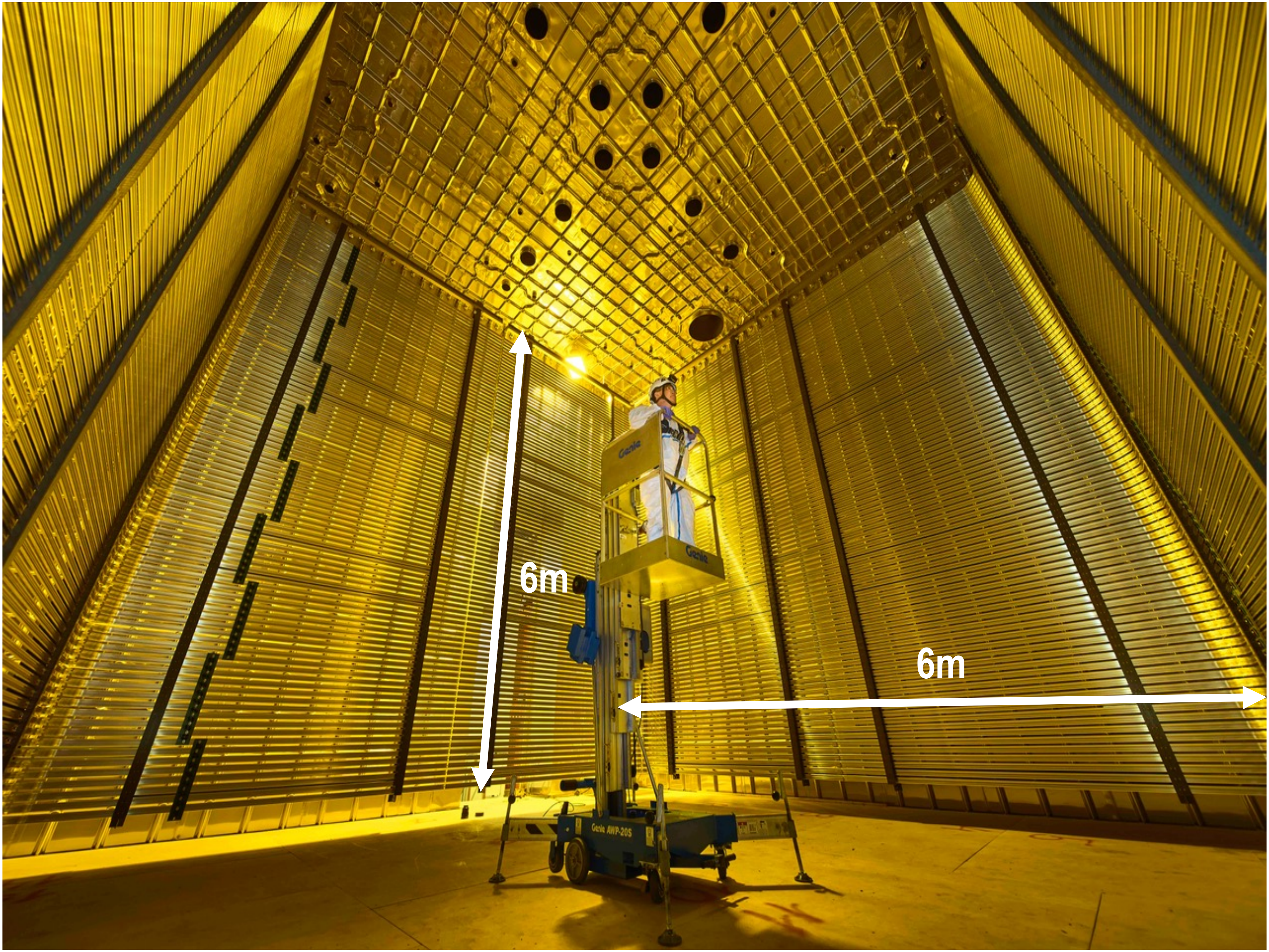
Valid for any space w/ dielectric w/ permittivity ε.

What is the stored energy in between ProtoDUNE cathode (-300kV) plate (6mx6m) and the cryostat wall (0V), d=1.5m, 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




6m
6m
Genie
Genie
Genie AWP-20S

DUNE Dual Phase