Capacitor Energy
Intro to Circuits

PHY 114-01

Fall 2026

Announcements

- More lecture activities
  - New standardized format
  - Full credit for participation

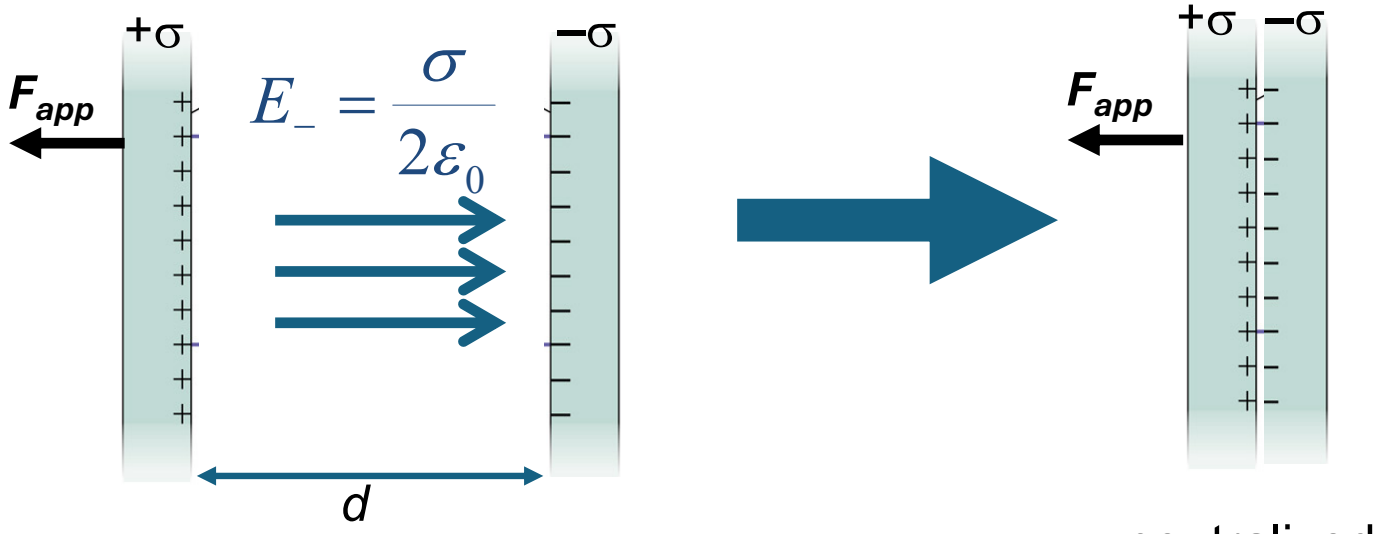
Agenda

- Last time:
  - Calculating capacitance
  - Capacitors in combination

- This time:
  - Capacitor energy
  - Intro to circuits:
    - Ohm’s law
    - Kirchoff’s laws

Energy Stored in a Capacitor

Key idea: The positive plate is in the electric field E_- of the **negative plate**. If the positive plate were free to move, it would crash into the negative plate, releasing energy



neutralized

To prevent it from crashing, we do work holding it back; and the **amount of work = energy stored=U_f-U_i**

Energy Stored in a Capacitor

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

Since $Q = CV$

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

ConceptCheck Energy in Capacitors

N identical capacitors, each of capacitance C, are connected in series. The circuit is charged via a potential difference V. The total stored energy is:

A. $\frac{1}{2} CV^2$

B. $\frac{1}{2} NCV^2$

C. $\frac{1}{2} CV^2/N$

D. $\frac{1}{2} CV^2/N^2$

E. none of the above

Equivalent capacitance=C/N, an *U* prop. to $\frac{1}{2} C_{eq} x V^2$

ConceptCheck Energy in Capacitors

Capacitor A has twice the capacitance of capacitor B. They are connected in parallel to a potential difference V. When B is charged to a stored energy *U*, the energy in A is:

A. ½ U
B. U
C. 2 U
D. 4 U
E. ¼ U

$U = ½ CxV^2$, so doubling C at same V doubles *U*

*** Daily quiz!**

Capacitors with Dielectrics

What happens if we fill the space between the plates of a capacitor with some insulating material, i.e., dielectrics? Michael Faraday investigated this in 1830's, and found the capacitance increases by some factor κ

- $C_{new} = \kappa C_{vacuum} \cong \kappa C_{air}$
- κ is called the dielectric constant (1 for vacuum)

Material	dielectric constant (κ)	dielectric strength (kV/mm)
Air	1.00054	3
polystyrene	2.6	24
transformer oil	4.5	
pyrex	4.7	14
water	~80	

Capacitors with Dielectrics

capacitance increases by a factor κ

- $C_{new} = \kappa C_{vacuum} \cong \kappa C_{air}$
- the permittivity constant becomes: $\varepsilon = \kappa \varepsilon_0$

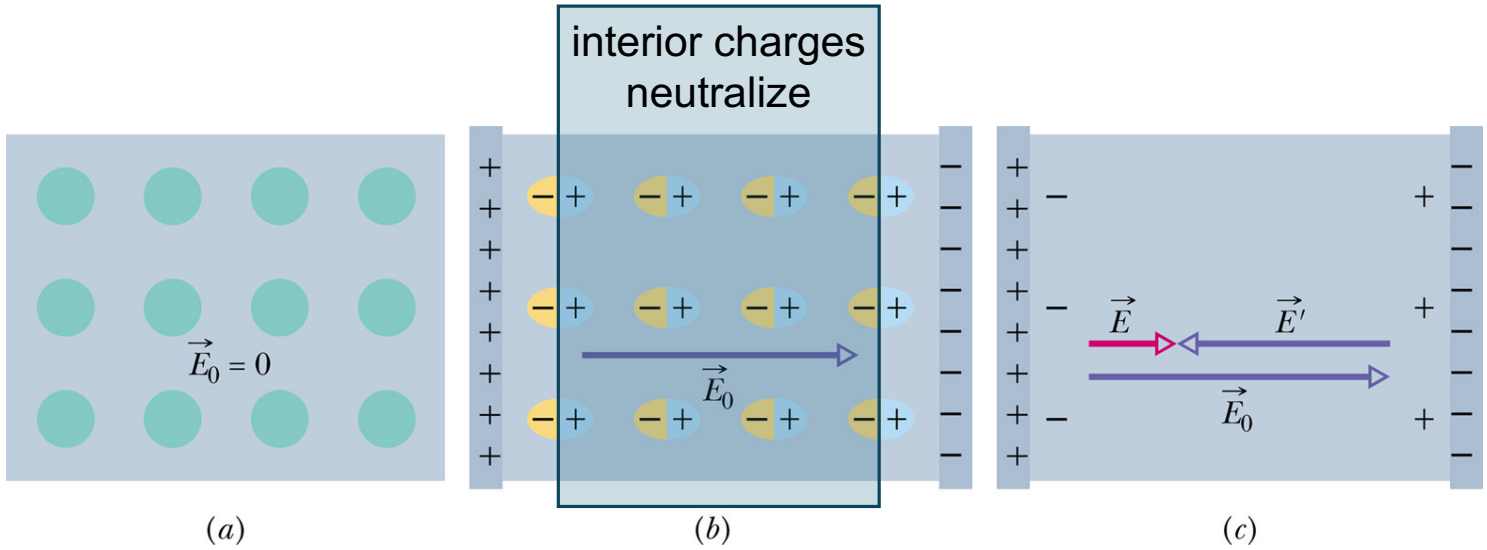
More generally:

In a region completely filled with a dielectric material with dielectric constant κ, all electrostatic equations have the permittivity constant ε_0 replaced with $\kappa\varepsilon_0$

E.g., for the parallel-plate capacitor filled with dielectrics,

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

Atomic view of a dielectric



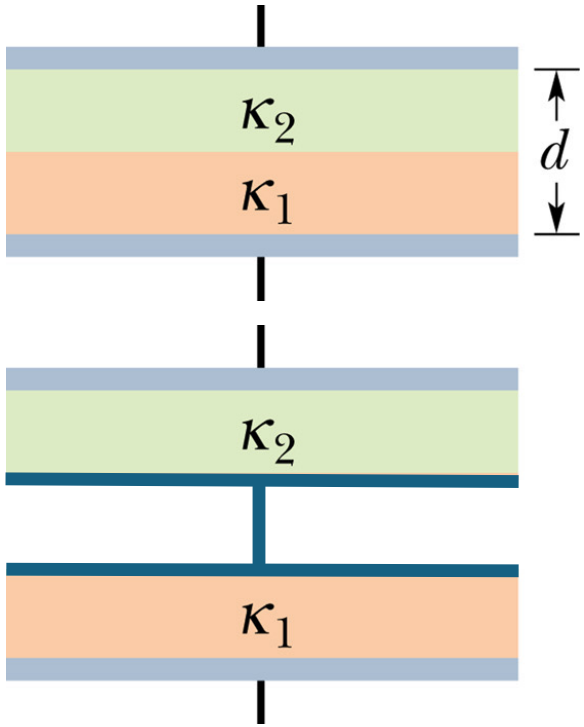
no applied field, unpolarized atoms

applied field polarizes atoms, causing opposite surface charges

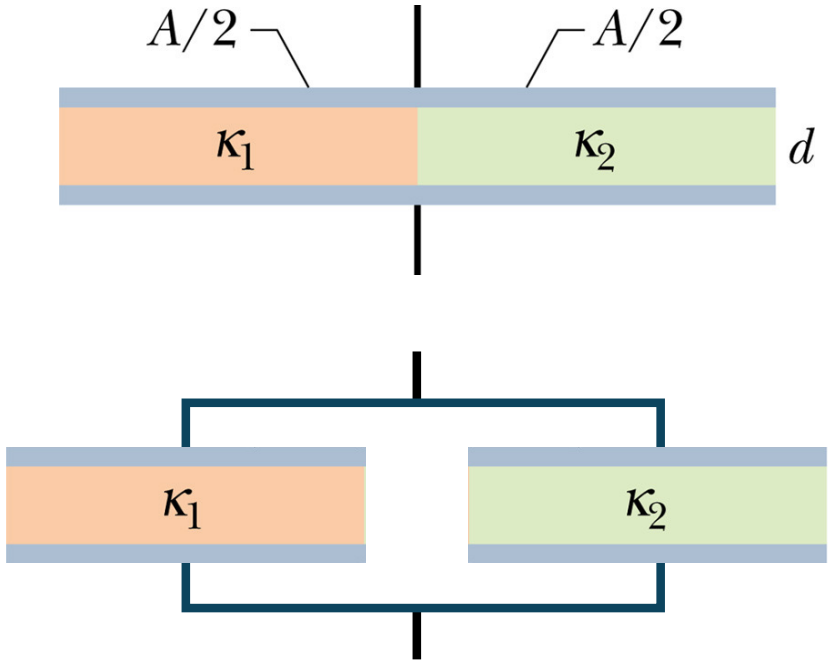
polarized charges oppose the applied field, $E = E_0 - E'$
➔reduced voltage,
➔increased C

Dielectrics in Capacitors

Given dielectrics mixed as shown, draw equivalent combination of capacitors so that each contains a pure dielectric



in series, each *d*/2



in parallel, each *A*/2

Problem: Capacitor with dielectrics

A 20.0 pF capacitor with a plate separation of 0.5 mm is connected to a 5V battery. If an insulator with dielectric constant κ =3.8 is inserted between the plates, how much does (a) the charge, and (b) the stored energy, change?

Key idea: V is constant during the process

(a) Find capacitance before and after insertion,
then $\Delta Q=(C' - C)V= (\kappa - 1)CV$

(b) Find energy before and after insertion,
then $\Delta U=U' - U$, or directly $\Delta U= \frac{1}{2} \Delta Q\, V$

Ans: ΔQ=280 pC, ΔU= 700 pJ