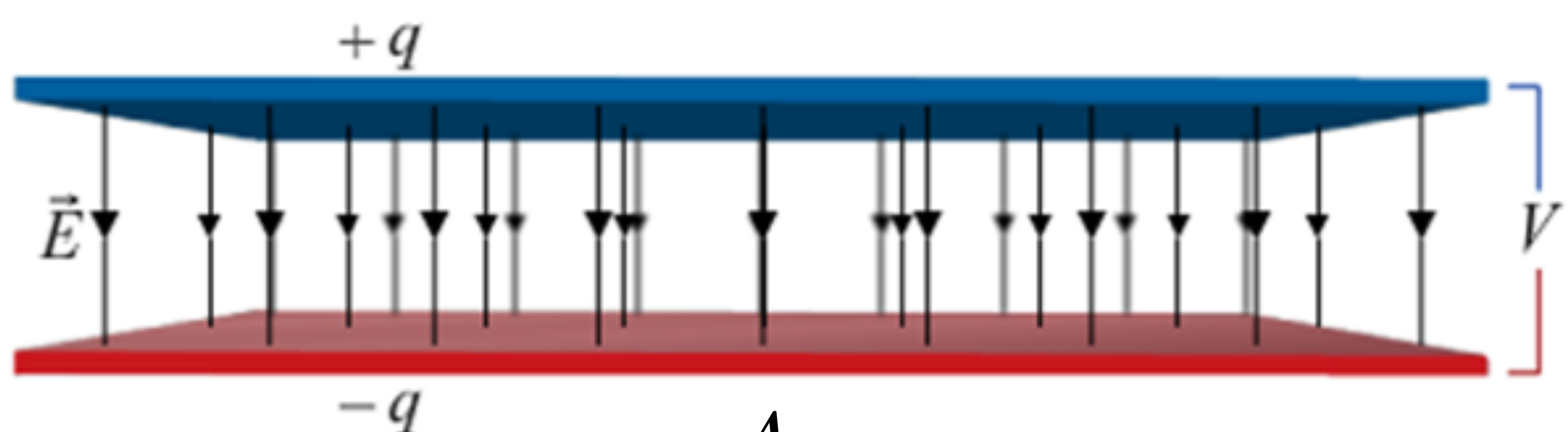
Dielectrics & Capacitors: Micro vs Macroscopic Electrostatics

Lecture 11

Review: Capacitance

- ***Capacitance***: *Capacity (or efficiency)* of conductor to hold charge at a potential difference.

$$Q = CV$$

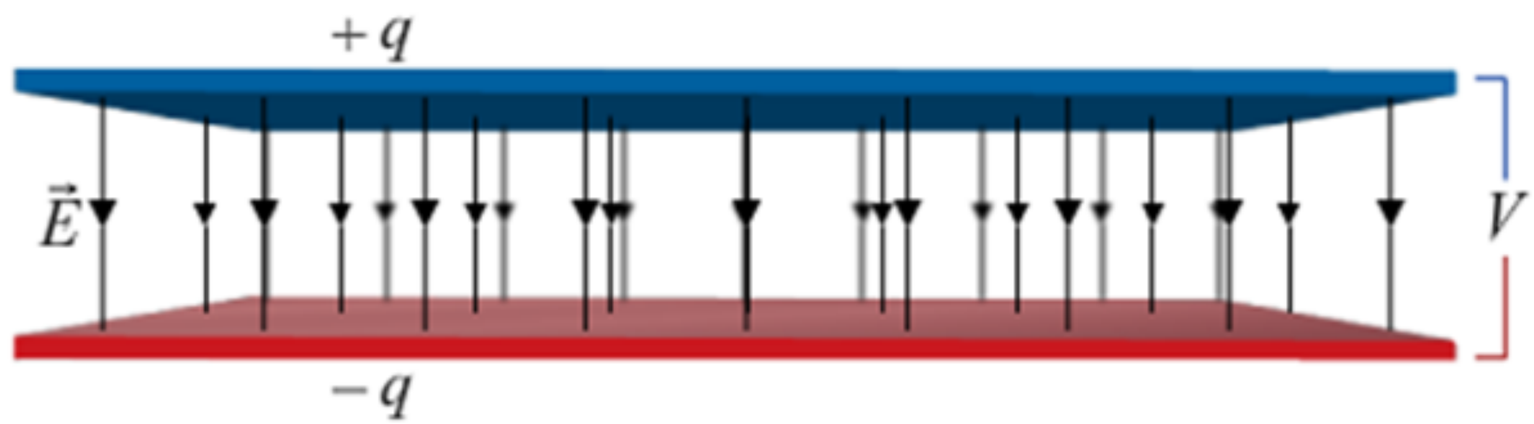


$$C = \frac{A\epsilon_0}{d}$$

- Units: Farad = C/V.

Review: **Energy** is stored in the **E field**

- Use a capacitor to compute the energy…



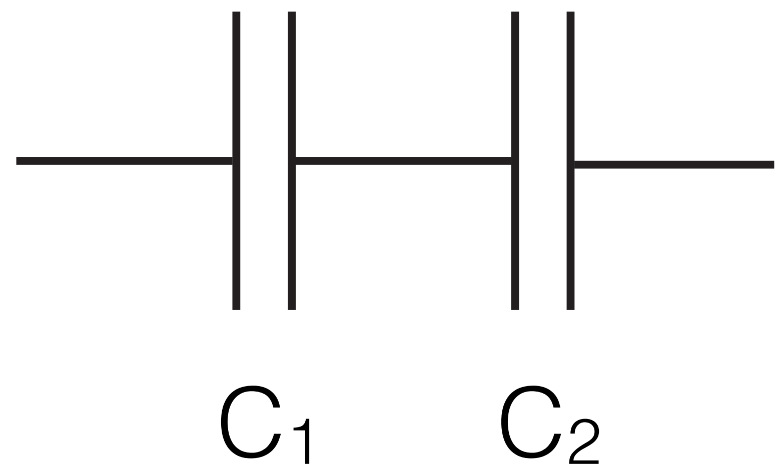
- **E is constant** inside capacitor so it will be easy to deduce the dependence on E

(overhead)

$$u = \tfrac{1}{2}\epsilon_0 E^2$$

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

Equivalent Capacitance for **Series Capacitors**

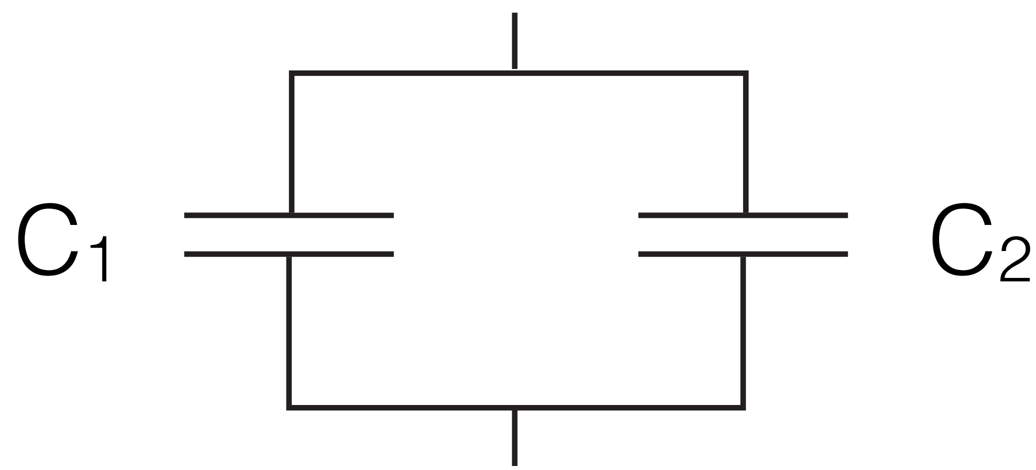


(overhead)

(~ Springs in series.)

$$C_{\mathrm{Equiv}}^{-1} = C_1^{-1} + C_2^{-1} = \sum_i C_i^{-1}$$

Equivalent Capacitance for **Parallel Capacitors**



(overhead)

(~ Springs in parallel.)

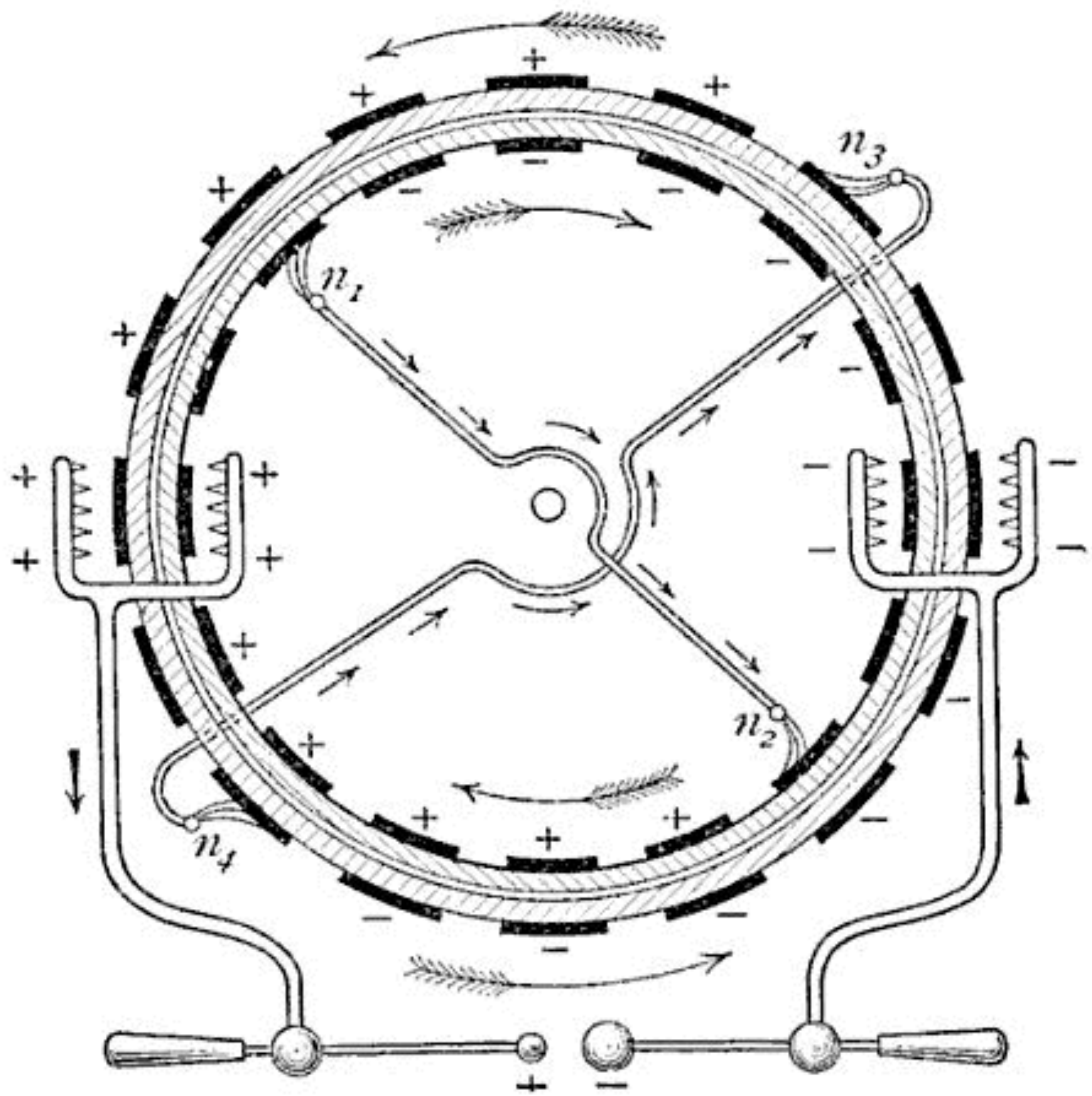
$$C_{\text{Equiv}} = C_1 + C_2 = \sum_i C_i$$

Capacitor networks

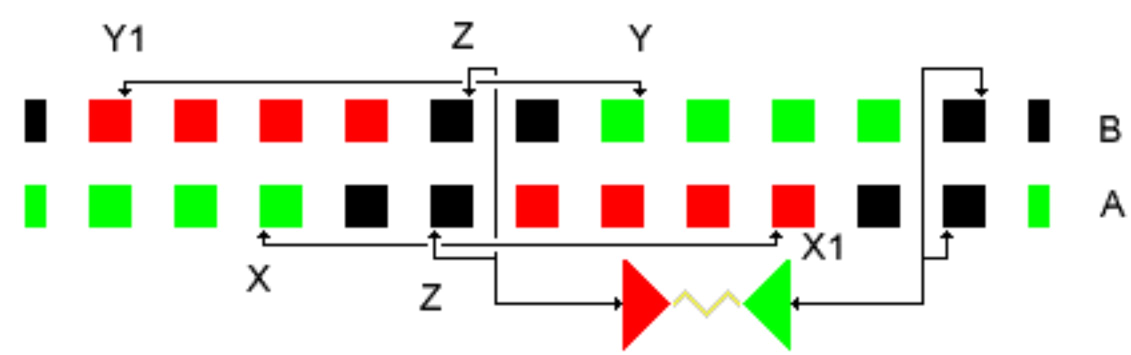
- (on board)

Clickers

Wimshurst Machine



- Influence machine
- Electrostatic charge generated by induction

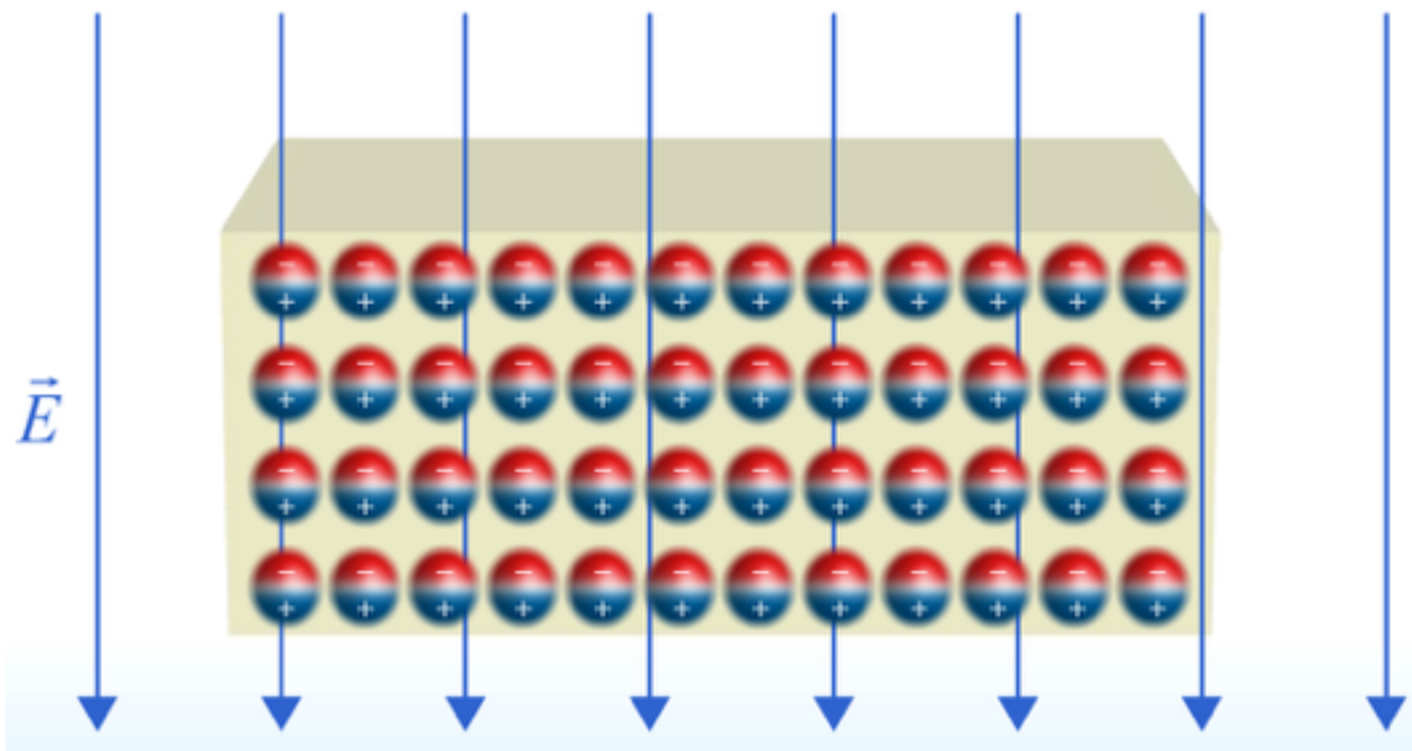


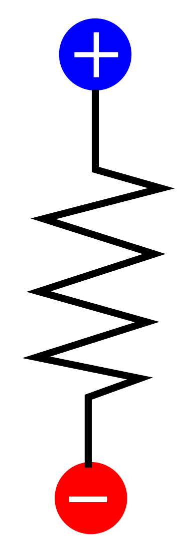
Demos

- Where is the charge?
- Dielectrics

Dielectrics: What is going on?

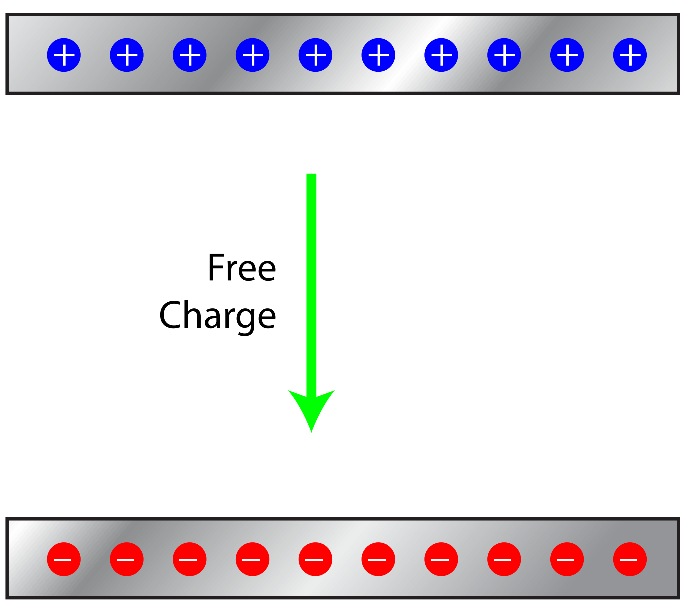
- External field **polarizes** dielectric





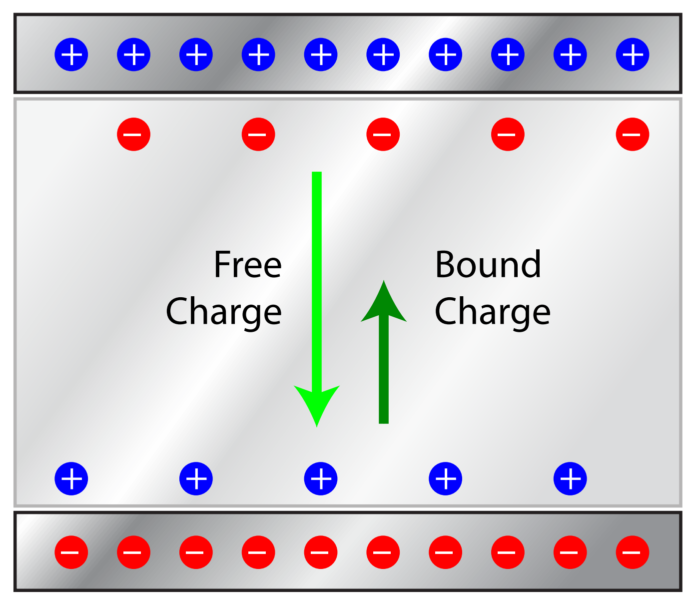
Dielectric: Induced Polarization

Insulator



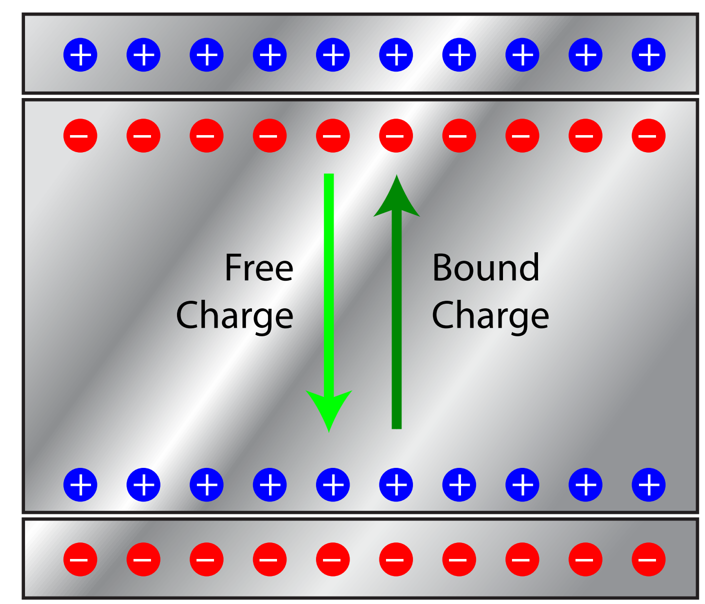
Effectively no bound charge. All fields generated by free charge only…

Dielectric



Dielectric is polarized by free charge, reducing E. Field generated by free and bound charge.

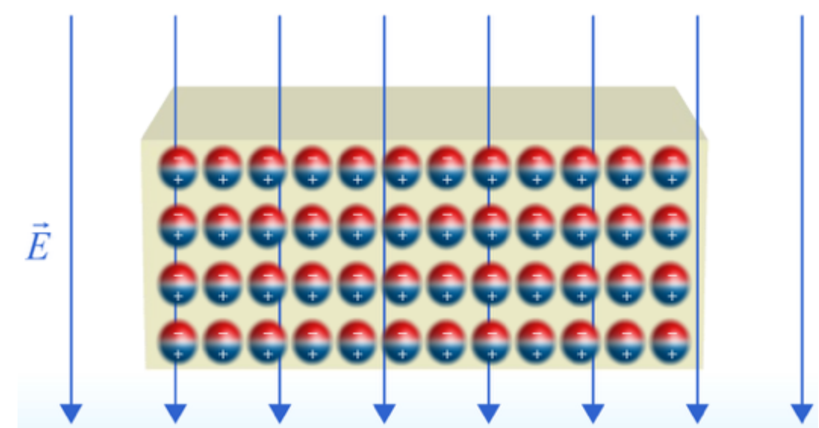
Conductor



Bound charge density is induced by free charge, completely canceling E field.

Electric field inside a dielectric

- External field **polarizes** dielectric
- Field from bound charge (E_B) cancels some of the field from the free charge (E_0).
- The total E field is:



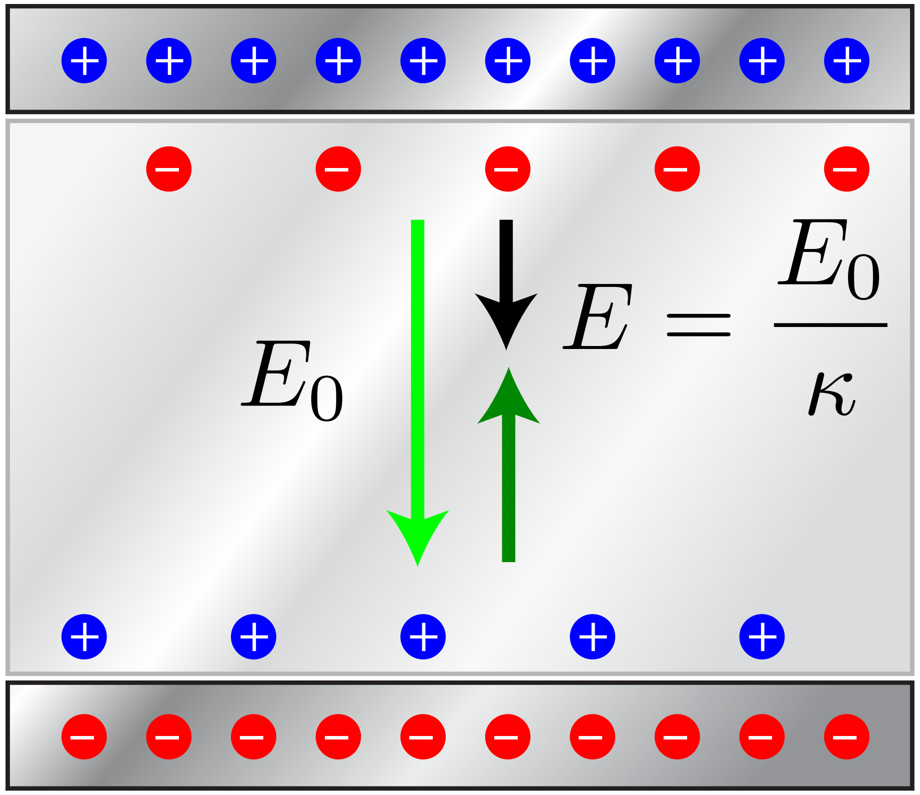
$$E = \frac{E_0}{\kappa}$$

- where $\kappa \geq 1$ is the dielectric constants

Capacitors with dielectric…

- What is the capacitance of a capacitor with dielectric?

  (overhead)



- Permittivity:

$$\epsilon = \kappa\epsilon_0$$

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

Why dielectrics?

Table 24-1 Dielectric Constants and Dielectric Strengths of Various Materials

Material	Dielectric Constant κ	Dielectric Strength, kV/mm
Air	1.00059	3
Bakelite	4.9	24
Gasoline	2.0 (70°F)	
Glass (Pyrex)	5.6	14
Mica	5.4	10–100
Neoprene	6.9	12
Paper	3.7	16
Paraffin	2.1–2.5	10
Plexiglas	3.4	40
Polystyrene	2.55	24
Porcelain	7	5.7
Strontium titanate	240	8
Transformer oil	2.24	12