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Dielectrics

- For a parallel-plate capacitor, $C = \frac{\epsilon_0 A}{d}$ (i.e. $C \propto \frac{1}{d}$)

- Since $Q = C\Delta V$, for a given A and ΔV, why does a smaller d mean more charge (Q) can be displaced?

→ Though it takes work to displace charge from one plate to another, this can be somewhat offset by having an attractive force due to opposite charges on the opposite plate
[another way to think about it is that we can store more energy in the electric potential because the attractive force between the two plates is ~~even~~ stronger when they are closer rather than farther apart]

⇒ However, in terms of 'making' capacitors, there is a limit on how small d can physically be made (as to how big A can reasonably be!)
[in real-life, capacitor come in an enormous range of physical sizes!]

⇝ one way to get around this is by placing an **insulator** inbetween the plate to essentially 'enhance' the electric field there (and thereby boost the capacitance)

Conductors [vs] Insulators

- Conductor (e.g. metal) → loosely bound valence electrons → 'sea of electrons' (easy for charge to 'flow')
- Insulator (e.g. plastic, glass) → tightly bound valence electrons → charges are immobile
  ⇒ an insulator can however be 'charged' (charge added/removed) and **polarized**

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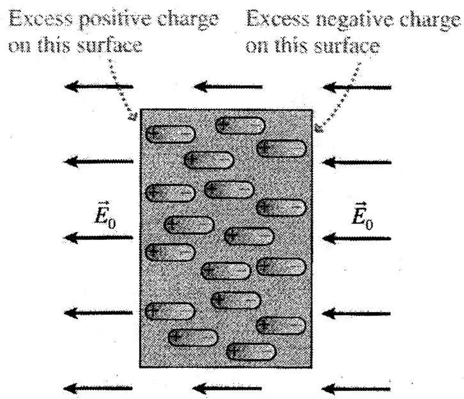
NOTE: Water is not a good conductor in itself. However, due to ions in water (e.g. dissolved salt, $NaCl \rightarrow Na^+ + Cl^-$), most liquid water does conduct electricity well

- When an insulator has charge placed across it (via an electric field), the fixed charges can become aligned w/ the field (see right)
  - → when placed in between the capacitor plates, we call this "polarized" insulator a **dielectric** (see below)
- this dielectric essentially causes an opposing $\bar{E}$ field (see next pg.)
  - → as a result, much more charge can be placed on the plates than before! (put another way, we can store more energy in it

FIGURE 29.31 An insulator in an external electric field.

(a) The insulator is polarized.



(b) The polarized insulator—a dielectric—can be represented as two sheets of surface charge. This surface charge creates an electric field inside the insulator.

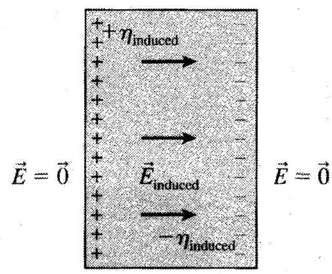
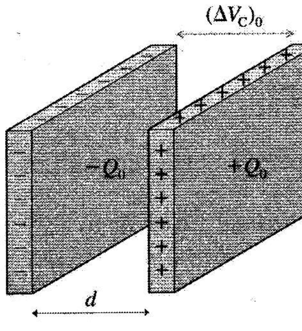


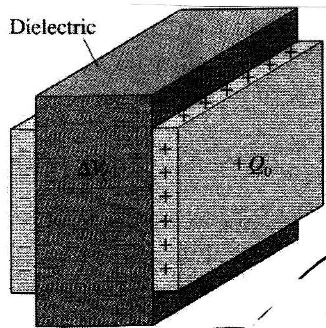
FIGURE 29.30 Vacuum-insulated and dielectric-filled capacitors.

(a)



Capacitance C_0 in vacuum

(b)



Capacitance $C > C_0$

why? (see next pg.)

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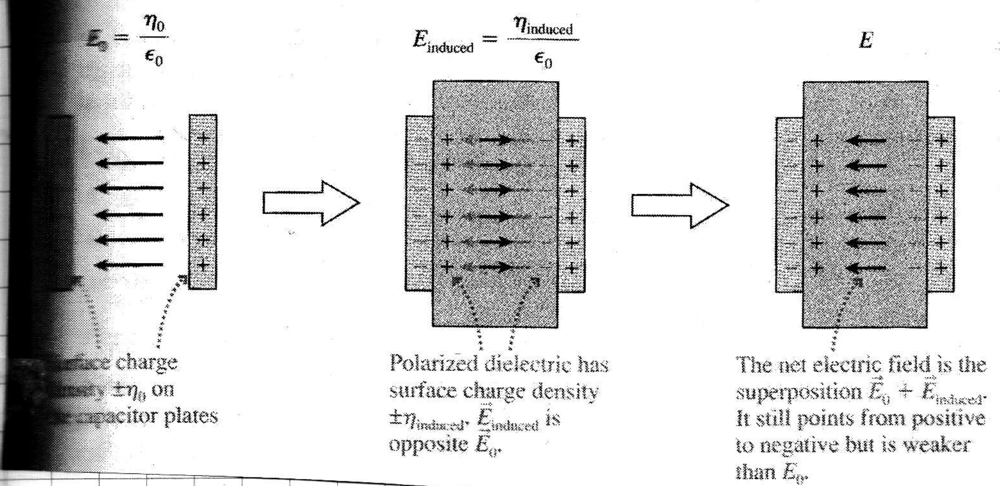
[…]RE 29.32 The consequences of filling a capacitor with a dielectric.



$\bar{E}_o$ - electric field w/o dielectric

$\bar{E}_{induced}$ - electric field induced inside dielectric (due to $\bar{E}_o$), points in opposite direction re $\bar{E}_o$

$\bar{E}_+$ - vector sum representing total electric field between plates w/ dielectric

$$\bar{E}_+ = \bar{E}_o + \bar{E}_{induced} < \bar{E}_o$$ (but points in same direction as $\bar{E}_o$)

- Now we define $K = \frac{|\bar{E}_o|}{|\bar{E}_+|} \longrightarrow K \geq 1$

ΔV - potential w/ dielect.
ΔV_o - potential w/o diel.

then $\Delta V = E_+ d = \frac{E_o}{K} d = \frac{\Delta V_o}{K}$

since $K \geq 1$, $\Delta V \leq \Delta V_o$

$$C = \frac{Q}{\Delta V} = \frac{Q_o}{\Delta V_o / K} = K \frac{Q_o}{\Delta V_o} = K C_o$$ $\longrightarrow$ capacitance <u>increased</u> by a factor of K

(assumes here $Q_o = Q$, so charge didn't change; see text)

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- Since $U = \frac{1}{2}C\Delta V^2$, for a fixed ΔV (e.g. that provided by a battery), increasing C via a dielectric increases the amount of electrical potential energy the capacitor stores

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

NOTE: the dielectric const. κ is a physical property (dimension-less) that can readily be measured (see Giordano table 29.1)

- Generally when ΔV is turned off, a dielectric loses its polarization. However, certain materials such as **ferroelectrics** can maintain their polarization and thereby used in a wide range of applications computer memory (e.g. RFID) and piezoelectrics

ex (revisit from 1/23)
A $1\,\mu F$ capacitor has plate separation 0.05 mm and is filled w/ strontium titanate as a dielectric ($\kappa = 300$). What is the surface area of the plates?

$$C = \frac{\kappa \epsilon_0 A}{d} \longrightarrow A = \frac{dC}{\epsilon_0 \kappa} = 0.019\ m^2$$

(or about 13 cm to a side if the plates are square, much smaller than 2.4 m per side w/o the dielectric!)