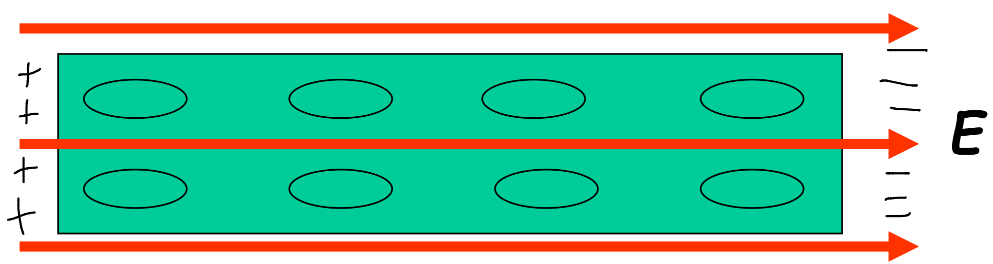
Dielectric Materials

What is a dielectric material?

- Dielectric materials consist of polar molecules which are normally randomly oriented in the solid.

- They are not conductors.

- When a dielectric material is placed in an external electric field, the polar molecules rotate so they align with the field. This creates an excess of positive charges on one face of the dielectric and a corresponding excess of negative charges on the other face.



Dielectric Material

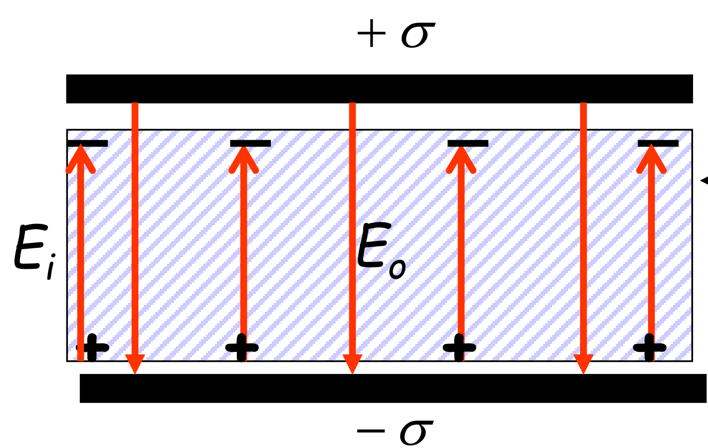
$\vec{E}$ is *smaller* in many materials than it would be in a vacuum for the same arrangement of charges.

37 : 10

3.7 : 1

Eg. <u>Parallel plates</u>:

$$E = \frac{E_o}{\kappa} = \frac{\sigma}{\kappa \varepsilon_o}$$



Dielectric material

Net field: $E = E_o - E_i$

*This makes the **potential difference smaller** (V=Ed) between the parallel plates of the capacitor for the same charges on the plates and thus **capacitance is larger**, since Q=C/V.*

Dielectric Constant

("kappa") = "dielectric constant"

κ = (a <u>pure number</u> ≥ 1)

So, $$\boxed{C = \frac{\kappa \varepsilon_o A}{d}}$$ (for parallel plates)

Or $$C = \kappa C_0$$

Where C_0 is the capacitance without the dielectric.

Hence, the capacitance of a filled capacitor is greater than an empty one by a factor κ

Material	$\underline{\kappa}$
Vacuum	1 (definition)
air	1.0006
paper	3.7
glass	~4 - 6
polystyrene	2.6
water	80

For any geometry:

$$\boxed{C = \kappa \cdot C_{vacuum}}$$

<u>i.e</u>. Replace "ε_0" with "$\kappa\varepsilon_0$" in the formulae.

Example: A parallel-plate capacitor has plates of 2cm by 3cm in dimension. The plates are separated by a 1mm thickness of paper. Paper with a dielectric constant of 3.7 is inserted between the plates.

What is the capacitance of this capacitor?

Example: The inner conductor of a coaxial cable has a radius of 0.800 mm, and the outer conductor's inside radius is 3.00 mm. The space between the conductors is filled with polyethylene, which has a dielectric constant of 2.30 and a dielectric strength of 18.0×10^6 V/m. What is the maximum potential difference that this cable can withstand?

$\Delta V = E_{max} \left(a - \ln \left(\frac{b}{a} \right) \right)$

$= a E_{max} \ln \left(\frac{b}{a} \right)$

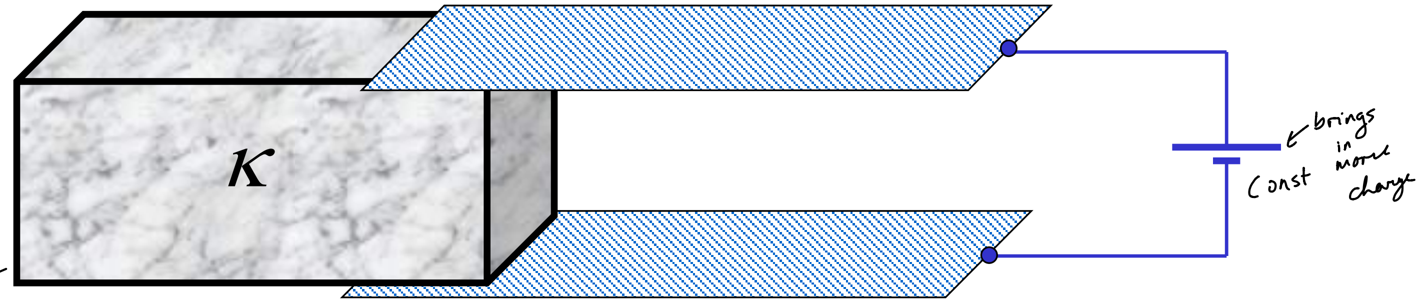
dielectric strength

So, $\Delta V_{max} = (0.8 \times 10^{-3})(1.8 \times 10^6 \, V \cdot m) \ln(3/0.8)$

$= 19 \, kV$

Quiz: What are the induced charges on the top/bottom of the dielectric as it is pushed between the plates?

$\uparrow C = kC_0 = k\frac{Q\uparrow}{V}$ same



What happens to the amount of charge on each plate as the dielectric material is pushed in between?

A) The charges on the plates increase
B) The charges on the plates decrease
C) No change in charges

Quiz

Two oppositely charged spheres are suspended a distance *d* apart in a beaker of distilled water. The force between them is

a) the same as if they were in air
b) larger
c) smaller

$$F = \frac{k q_1 q_2}{r^2}$$

$$= \frac{1}{\underbrace{4\pi\varepsilon_0}_{\kappa\varepsilon_0}} \frac{q_1 q_2}{r^2}$$

Why use dielectrics in capacitors?

1) the capacitance is increased by a factor κ
2) the dielectric material gives mechanical strength (holds the conductors apart)
3) the plate separation can be smaller (which also increases capacitance) : $C=Q/V=Q/(Ed)$
4) the "dielectric breakdown", or maximum electric field before conduction between the plates starts, can be higher than for air, allowing higher voltage ratings

Dielectric Breakdown

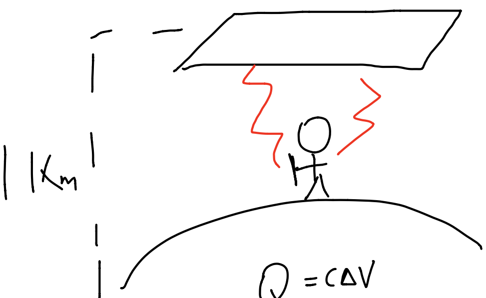
There is a maximum voltage that can be applied to a capacitor without causing a discharge.
his voltage depends on the dielectric strength (maximum electric field intensity) of the dielectric.

Eg: for air, this is 3×10^6 V/m

For many materials the strengths are in the 10^6 V/m range.

Example

Air breaks down at 3×10^{6} V/m. Assuming that storm clouds are 1km above the earth, approximate the maximum charge that they can store (assume the cloud to be a 1km by 1km rectangle).



$$Q = C\Delta V$$
$$= 26C$$

$$V_{max} = E_{max} d$$
$$= (3\times10^{6}\,V/m)(1000m)$$
$$= 3\times10^{9}\,V$$

$$C = \frac{k\varepsilon_0 A}{d} = 8.85\times10^{-9}F$$

Summary of Capacitance

$$C = \frac{Q}{V}$$

+Q on one conductor, -Q on the other conductor

Potential difference between them

Deriving Formulae: (for plates, spheres, cylinders)

1) Assume charges +Q, -Q
2) Calculate E from Gauss's Law
3) Integrate along a field line: $V = -\int \vec{E} \bullet d\vec{s}$
4) $C = \frac{Q}{V}$