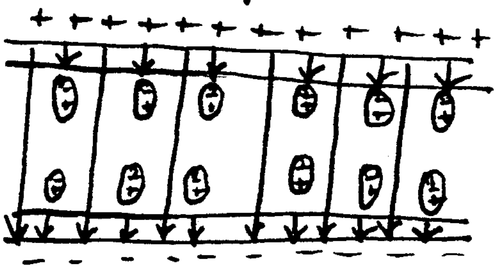
MAT'L	DIELECTRIC CONSTANT	DIELECTRIC STRENGTH kV/mm
VACUUM	1.0000000 000000	∞
AIR	1.0005	1
WATER	1.01	
MICA	7.5	
CELL MEMBRANE	8	
POLYETHELENE	2.3	20
PAPER	1.7-4.0	highly variable

How does this happen? Electric field polarizes charges in dielectric creating



net - charge next to + plate and net + charge on surface next to - plate.

In vacuum

$$E_0 = \frac{V}{l} = \frac{\sigma}{\varepsilon_0} \text{ between plates}$$

Since V is smaller with dielectric between plates ⟹ E is also reduced within dielectric due to charges induced on the surface

If a chg density σ_i is induced on the dielectric surface we may write

$$E = \frac{V}{l} = \frac{\sigma - \sigma_i}{\varepsilon_0} \text{ in dielectric}$$

Q Same

From above

$$K = \frac{C}{C_0} = \frac{Q/V}{Q/V_0} = \frac{V_0}{V} = \frac{E_0}{E}$$

$$K = \frac{\sigma/\varepsilon_0}{\sigma - \sigma_i/\varepsilon_0} \Rightarrow \sigma - \sigma_i = \frac{\sigma}{K}$$

Substituting above

$$E = \frac{\sigma}{K\varepsilon_0} \text{ or } \frac{\sigma}{\varepsilon}$$

where $\boxed{\varepsilon = K\varepsilon_0}$

The quantity ε is called the "permittivity" of a material. For vacuum $K = 1$ $\varepsilon = \varepsilon_0$ ~~thus~~ ε_0 is the permittivity of vacuum or free space. For ∥ plate capacitor

$$C = KC_0 = Kc_0\frac{A}{l}$$

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

For dielectric use ε in place of ε_0

If $\vec{E}$ gets too high lattice bonds between atoms + molecules breakdown charges can move and the dielectric becomes a conductor. This phenomena is known as <u>dielectric breakdown</u>

The <u>dielectric</u> <u>strength</u> of a material is the $\overset{\max}{}$ E field it can stand before breakdown. Vacuum ∞, Air $1\ \mathrm{kV/mm} \Rightarrow$ a capacitor w/ separation $1\,\mathrm{mm}$ would be able to withstand a voltage of $1\,\mathrm{kV}$ before ionizing air + breaking down.

<u>e.g.</u> $\parallel$ plates separated by polyethelene

<u>Sep</u> $0.1\ \mathrm{mm}$ $\quad A \approx (3\,\mathrm{ft})^2 \approx \overset{1.0}{\cancel{0.1}}\ \mathrm{m}^2$

$$C_0 = \varepsilon_0 \frac{A}{l} = \frac{\overset{1.0}{\cancel{0.1}}\,\mathrm{m}^2}{10^{-5}\,\mathrm{m}} \cdot 8.85\times10^{-12}\,C^2N^{-1}m^{-2}$$

$$\approx \overset{1.0}{\cancel{0.1}}\ \mu F$$

Breaks down at $V = 1\,\mathrm{kV/mm} \cdot 0.1\,\mathrm{mm} = 100\,\mathrm{V}$

$C = K\,C_0 = 2.3 \times 0.1\,\mu F = 0.23\,\mu F$

Breaks down at $V = 20\,\mathrm{kV/mm} \cdot 0.1\,\mathrm{mm} = 2\,\mathrm{kV}$

Why all this big deal about dielectrics
Serve three important practical functions

1) increase C for given capacitor size
2) increase capability of running at high V over air
3) can keep small but constant separation between conductors

Actually make capacitors out of sheets of metal foil sep by mylar or polyethylene + roll up into compact cylinder.

Recall Cyl

$$E = \frac{2k\lambda}{r} \qquad V = \int E_\parallel \, ds$$

$$\Rightarrow V = 2k\lambda \int_{r_a}^{r_b} \frac{1}{r} \, dr$$

$$= 2k\lambda \ln r \Big|_{r_a}^{r_b}$$

$$= 2k\lambda \ln r_b/r_a$$

$$C = \frac{Q}{V} \qquad Q = \lambda L$$

$$k = \frac{1}{4\pi\varepsilon_0}$$

$$C = \frac{\cancel{\lambda} L}{2k\cancel{\lambda} \ln r_b/r_a} = 2\pi\varepsilon_0 \frac{L}{\ln r_b/r_a}$$

Cylindrical Capacito