Properties of dielectrics

1. Dielectrics do not contain any free charges but contain bound charges

2. Bound charges are under the internal molecular and atomic forces and cannot contribute to the conduction.

3. When subjected to an external field E, the bound charges shift their relative positions. Due to this small electric dipoles are induced.

4. Due to the polarization dielectrics can store the energy.

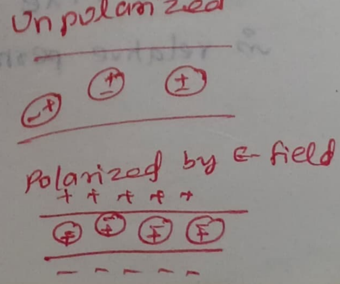
Polarization

When an electric field E is applied, the positive charge is displaced from its equilibrium position in the direction of E by the force F = QE, while the negative charge is displaced in the opposite direction by the force F = -QE.

A dipole results from the displacement of charges and the dielectric is said to be polarized.

we can define polarization in (coulombs per m^2) as the dipole moment per unit volume of the dielectric.

$$P = \lim_{\Delta v \to 0} \frac{\sum_{k=1}^{N} Q_k d_k}{\Delta v}$$



There are two types of dielectrics,

1. Nonpolar
2. Polar

Nonpolar molecules do not posess dipoles until the application of the electric field.

Eg: Hydrogen, oxygen, nitrogen

Polar modecules have built-in permanent dipoles that are randomly oriented.

Eg: water, sulfur dioxide, HCl;

Polarization increases the electric flux density in a dielectric medium.

flux density in a dielectric is,

$\bar{D} = \varepsilon_0 \bar{E} + \bar{P}$

$\bar{P} = \chi_e \varepsilon_0 \bar{E}$

χ_e → electric susceptibility → How sensitive is a given dielectric to the applied field.

$\bar{D} = \varepsilon_0 \bar{E} + \chi_e \varepsilon_0 \bar{E}$

$= (\chi_e + 1) \varepsilon_0 \bar{E}$

$\bar{P} = \varepsilon_r \varepsilon_0 E$

$\varepsilon_r = 1 + \chi_e$

is relative permittivity or dielectric constant.

Conductors & Electric field.

* A perfect conductor ($\sigma = \infty$) cannot contain an electrostatic field within it. *

When an external electric field is applied, the '+ve' free charges are pushed along the same direction as the applied field, while the negative free charges ~~are~~ move to the opposite direction.
They accumulate on the surface of the conductor and form an induced surface charge.
Induced charges set up an internal induced field E_i, which cancels the externally applied field E_e.

$E = 0$,
$\rho_v = 0$,
$V_{ab} = 0$
} inside a conductor.

V_{ab} ~~a & b~~ is the pot. diff b/w points a & b in the conductor.

Dielectric constant & Strength

WKT $D = \varepsilon_0 (1 + \chi_e) E$

$= \varepsilon_0 \varepsilon_r E$

$D = \varepsilon E$

where $\varepsilon = \varepsilon_0 \varepsilon_r$

$\varepsilon_r = 1 + \chi_e = \frac{\varepsilon}{\varepsilon_0}$

High ε_r material.

oxides of $ACu_3Ti_4O_2$

Perovskite related oxide containing Ca, Cu, Ti & O

$CaCu_3Ti_4O_{12}$.

→ Extremely high ε_r = 12,000.

ε is called the permittivity of the dielectric.

ε_0 is the permittivity of free space.

ε_r is the dielectric constant or relative permittivity.

* The dielectric constant (or) relative permittivity is the ratio of the permittivity of the dielectric to that of the free space.

materials for Semiconductor ICs ⟵ High dielectric constant → more charge can be stored & smaller electronic ckt & High capacitance values required

ε_r & χ_e are dimensionless whereas ε & ε_0 are in farads per meter.

To reduce the resonator size, increase in ε_r, diameter $\alpha \frac{1}{\sqrt{\varepsilon_r}}$

ε is always $\varepsilon_r \geq 1$

The minimum value of the electric field at which dielectric breakdown occurs is called the dielectric strength of the dielectric material.

(Dielectric breakdown is said to have occurred when a dielectric becomes conducting).

Gaseous dielectrics experience breakdown [lightning]

Unit V/m

* The dielectric strength is the maximum electric field that a dielectric can tolerate or withstand without electrical breakdown.

mica < 118 mV/m
Glass = 9.8 to 13.8

Linear, Isotropic and Homogeneous Dielectrics:

(Polarization parallel to field) Isotropic

A material is said to be linear if D varies linearly with E and otherwise nonlinear.

Materials for which ε (or σ) does not vary in the region being considered and same at all points (independent of x, y, z) are said to be homogeneous.

High dielectric constants – materials in high performance electric devices.

Barium strontium titanate (BST) – plan for DRAMS. | RFID chips-

They are said to be inhomogeneous when ε depend on the space coordinates.

Materials for which D and E are in the same direction are said to be isotropic.

<u>For conductors:</u>

The same idea holds for a conducting material in which $J = \sigma E$ applies. The material is linear if σ does not vary with E, homogeneous if σ is same at all points, and isotropic if σ does not vary with direction.

Boundary Conditions:

If the electric field exists in the region consisting of two different media, the conditions that the field must satisfy at the interface separating the media are called boundary conditions.

Boundary conditions at an interface separating

- Dielectric (ε_{r1}) & Dielectric (ε_{r2})
- Conductor & dielectric
- Conductor & free space

require high capacitance to store charge.

Method of Images:

It is used to determine V, E, D and ρ_s due to charges in the presence of Conductors. By this method,

* we avoid solving Poisson's & Laplace's equation

but

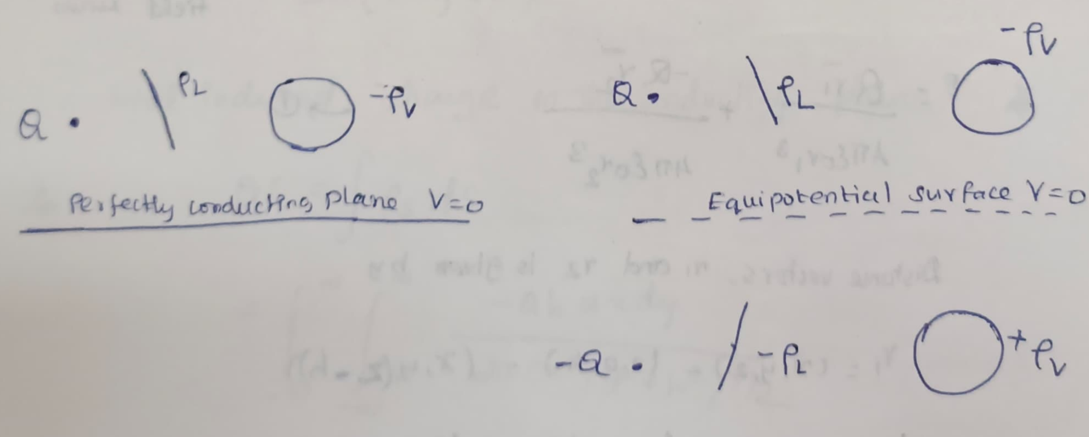
* utilize the fact that a conducting surface is equi-potential.

Advantage :- simple one

Disadv. :- This method does not apply to all electrostatic Problems.

"Image theory states that a given charge configuration above an infinite grounded perfect conducting plane may be replaced by the charge configuration itself, its image and an equipotential surface in place of conducting plane".

(a) Point, line, volume charge configurations (b) Image configurations



Two conditions must be Satisfied:

1. The image charge(s) must be located in the conducting region. (satisfy poisson's eqn)
2. The image charge(s) must be located such that on the Conducting surfaces the potential is zero or constant. (satisfy boundary conditions)