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B.Sc (PS) Computer Science VI Sem
Dielectrics 2

It is greater than one and independent of shape or the dimensions of the capacitor but varies for different dielectric materials (medium). The Permittivity of the medium (ϵ) is defined as

$$\epsilon = \epsilon_0 \epsilon_r = \epsilon_0 K$$

$$\epsilon_r = K = \epsilon / \epsilon_0 \quad \text{--- (4)}$$

Thus the dielectric Const (K) is also defined as the ratio of the permittivity of the medium to the permittivity of the vaccum, K for air or vaccum is equal to unity

Three electric Vectors: E, P and D

(i) Electric field Intensity E: The electric field Intensity at any point in the Electric field is defined as the force experienced by a unit +ve charge placed at that point.

$$\vec{E} = \lim_{q \to 0} \frac{\vec{F}}{q} \quad \text{--(5)} \quad \vec{E} \ \& \ \vec{F} \text{ are same direction}$$

$$E = \frac{q}{\epsilon_0 A} \quad (\text{N/Coulomb or V/m}) \text{ --- (6)}$$

(ii) Polarization Vector $\vec{P}$:- In the Presence of an electric field, the molecules of a dielectric become polarized and gain electric dipole moment. The effect is called electric polarization. The Polarization Vector is defined as electric dipole moment induced per unit volume. It has the same direction as the electric field and denoted by $\vec{P}$ (C/m^2) (Coullomb/m^2).

If σ_p is the density of Polarization charge on the surface, P (Polarization Vector), A is the area of Crossection & l is the length of dielectric

Slab, lA the volume, then
Dipole moment of dielectric $= PlA$
Considering this dielectric slab as a single dipole with surface charges ($= \sigma_p A$), seprated by a distance l, then
Dipole moment = charge X length $= \sigma_p A l$
Comparison gives
$$P = \sigma_p$$
Thus Polarization Vector $\vec{P}$ depends on induced surface density.

(iii) Electric displacement Vector D:-
When a dielectric placed in the parallel plates of a capacitor, E_0 is the external electric field applied, the dielectric gets polarized. If q_0 is the charge on the plates of capacitor and q' is the induced charge on the boundary of dielectric, the resultant field is
$$\vec{E} = \vec{E_0} - \vec{E_p}$$
where $\vec{E_0} = \frac{q_0}{\epsilon_0 A}$ and $\vec{E_p} = \frac{q'}{\epsilon_0 A}$.
$$\text{Thus } \vec{E} = \frac{q_0}{\epsilon_0 A} - \frac{q'}{\epsilon_0 A}$$
but q'/A is the surface density of the induced charge, called the electric Polarization P. ∴
$$\epsilon_0 \vec{E} = \frac{q_0}{A} - \vec{P}$$
$$\text{or } \frac{q_0}{A} = \epsilon_0 \vec{E} + \vec{P}$$
The quantity on the left is the free surface density and called electric displacement D and measured in Coulomb/m². Thus
$$\vec{D} = \epsilon_0 \vec{E} + \vec{P} \quad — (7)$$

where $\vec{D}$ is the electric displacement vector or the flux density and is defined as the number of lines of forces received by a unit area.

In free space, when no dielectric $P=0$,

$$\text{then} \quad D = \epsilon_0 E \qquad \text{—(8)}$$

$$\text{with } D = \frac{q_0}{A} = \epsilon_r \epsilon_0 \left(\frac{q_0}{K \epsilon_0 A} \right) = \epsilon_r \epsilon_0 \left(\frac{q_0}{\epsilon A} \right)$$

$$\text{or} \quad \vec{D} = \epsilon_r \epsilon_0 \vec{E} \qquad \text{—(9)}$$

$$\text{or} \quad \vec{D} = \epsilon \vec{E} \qquad \text{—(10)}$$

where the product $\epsilon_r \epsilon_0$ is called the permittivity ϵ of the medium. The dielectric constant ϵ_r is defined as the ratio ϵ / ϵ_0 and also called relative permittivity. The permittivity is defined as the ratio of electric displacement D to the electric field intensity in dielectric.

Electric susceptibility :-

The Phenomenon of electric polarization occurs when a dielectric is placed in an electric field. Accordingly, the three electric vectors $\vec{E}$, $\vec{P}$ & $\vec{D}$ are related as

$$\epsilon_0 \vec{E} + \vec{P} = \vec{D}$$

$$\text{but} \quad \vec{D} = \epsilon_r \epsilon_0 \vec{E} \qquad \text{(from eq. 9)}$$

$$\therefore \quad \vec{P} = \epsilon_r \epsilon_0 \vec{E} - \epsilon_0 \vec{E}$$

$$\text{or} \quad \vec{P} = \epsilon_0 (\epsilon_r - 1) \vec{E} \qquad \text{---(11)}$$

$$\vec{P} = \epsilon_0 \chi_e \vec{E} \qquad \text{—(12)}$$

$$\text{where } \chi_e = (\epsilon_r - 1)$$

$$\text{or } \chi_e = \frac{P}{\epsilon_0 \vec{E}} \qquad \text{—(13)}$$

where χ_e is called the electric susceptibility of dielectric and is characteristics of the material.

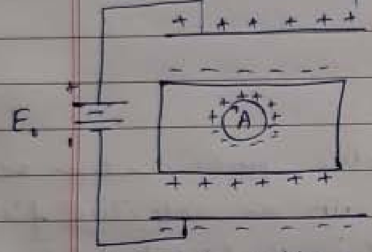
The electric susceptibility of the dielectric may be defined as the ratio of Polarization to the product of electric field intensity in the dielectric and free space permittivity. Dielectric susceptibility is dimensionless.

$$\chi_e = \epsilon_r - 1$$

$$\boxed{\epsilon_r = 1 + \chi_e}$$

Local field in Dielectric:-

The local field is the effective electric field which polarize the dielectric and also called molecular field. This field is due to the external applied field as well as the other dipoles in the system. The evaluation of this field was done by Lorentz as follows:



Dielectric with a cavity in an external electric field

Let there be a spherical cavity in the dielectric of radius r and centre A, such that the radius r is large compared with intermolecular distance. Thus the sphere contains many molecules but small compared with the dimensions of whole dielectric.

If this dielectric is placed between two charged parallel plates in the fig. the effective field experienced by the molecule of the dielectric, if assumed to be placed at the centre of the cavity, is given by

$$E_{loc} = E_0 + E_1 + E_2 + E_3$$

Where → E_0 is the field intensity between the two charged parallel plates without dielectric.

→ E_1 is the field at the atom due to polarized charges on the outer surfaces of the dielectric.

→ E_2 is the field due to all the dipoles inside the spherical cavity

→ E_3 is the field due to polarized charges on the inner surface of the spherical cavity.

$$\text{Now } D = \epsilon_0 E_0 = \epsilon_0 E + P$$

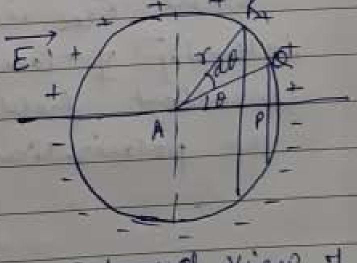
$$\text{or } E_0 = \frac{D}{\epsilon_0} = E + \frac{P}{\epsilon_0} \qquad \text{--- (i)}$$

$$\text{Also } E_1 = -\frac{D}{\epsilon_0} = -\frac{P}{\epsilon_0} \qquad \text{--- (ii)}$$

taking $E=0$ in eq. (i), as E_1 is the depolarizing field.

fields of dipoles, E_2: If all the atoms are assumed to be replaced by point dipoles parallel to each other, then the field E_2 due to atoms within the cavity will depend on the crystal structure. There are number of cases in which this term vanishes for cubic crystal with spherical cavity, $E_2 = 0$. Since the cavity is only imaginary, ~~the~~ the result holds good for a cubic crystal of spherical shape for other crystal structures, $E_2 \neq 0$ e.g Monoclinic, triclinic, hexagonal etc.

Calculation of field E_3:- E_3 is the field intensity at A due to polarization charges on the surface of the cavity and is calculated as below:-



Enlarged View of cavity

The enlarged view of the cavity is shown in the fig. If dA is the surface area of the sphere of radius r lying between charges on the outer surface of the dielectric.

→ E_2 is the field due to all the dipoles inside the spherical cavity

→ E_3 is the field due to polarized charges on the inner surface of the spherical cavity.

Now $D = \epsilon_0 E_0 = \epsilon_0 E + P$

or $E_0 = \frac{D}{\epsilon_0} = E + \frac{P}{\epsilon_0}$ ——— (i)

Also $E_1 = -\frac{D}{\epsilon_0} = -\frac{P}{\epsilon_0}$ ——— (ii)

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Since the cavity is only imaginary, ~~this~~ the result holds good for a cubic crystal of spherical shape. For other crystal structures, $E_2 \neq 0$ e.g. Monoclinic, triclinic, hexagonal etc.

Calculation of field E_3:- E_3 is the field intensity at A due to polarization charges on the surface of the cavity and is calculated as below:-

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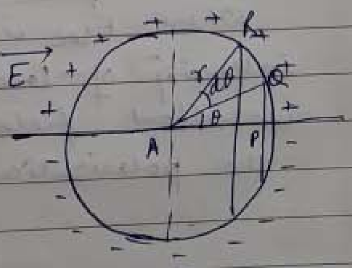


Enlarged view of cavity

θ and $\theta + d\theta$, where θ is the direction with reference to the direction of the applied field, then

$$dA = 2\pi (PQ)(QR)$$

$$dA = 2\pi r \sin\theta \, r d\theta$$

$$= 2\pi r^2 \sin\theta \, d\theta$$

The charge dq on the surface dA is equal to normal component of the polarization multiplied by the surface area. Thus

$$dq = \vec{P}\cos\theta \, dA = \vec{P}(2\pi r^2 \sin\theta \cos\theta \, d\theta)$$

The field due to this charge at A is dE_3 in the direction $\theta = 0$ and given as

$$d\vec{E}_3 = \frac{dq \times 1 \times \cos\theta}{4\pi\epsilon_0 r^2} = \frac{\vec{P}\cos\theta \, 2\pi r^2 \sin\theta \cos\theta \, d\theta}{4\pi\epsilon_0 r^2}$$

$$\text{or } d\vec{E}_3 = \frac{\vec{P}}{2\epsilon_0} \cos^2\theta \sin\theta \, d\theta$$

The total field $\vec{E}_3$ due to charges on the surface of the entire cavity is obtained by integrating

$$\int d\vec{E}_3 = \vec{E}_3 = \frac{\vec{P}}{2\epsilon_0} \int_0^{\pi} \cos^2\theta \sin\theta \, d\theta$$

$$E_3 = \frac{P}{2\epsilon_0} \cdot \frac{2}{3} = \frac{P}{3\epsilon_0}$$

$$\text{So } E_{loc} = E + \frac{P}{\epsilon_0} - \frac{P}{\epsilon_0} + 0 + \frac{P}{3\epsilon_0}$$

$$\boxed{E_{loc} = E + \frac{P}{3\epsilon_0}}$$

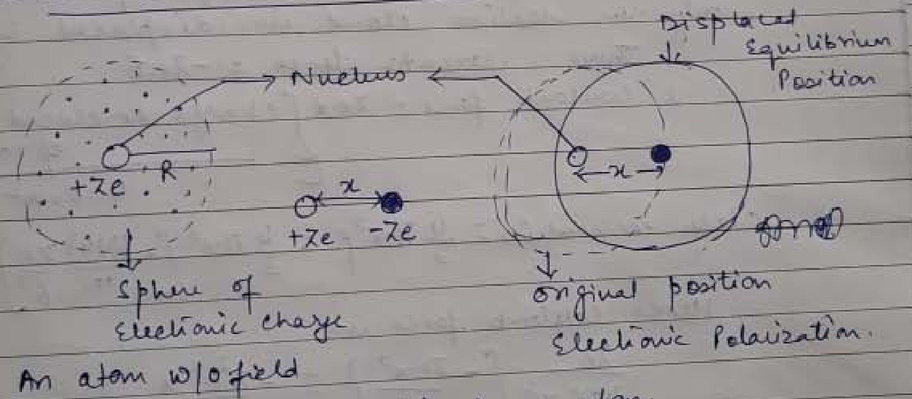
Where E_{loc} is called Lorentz field. The intensity of Lorentz field is larger than the resultant field by an amount proportional to the polarization density.

Types of Polarization:-

The dielectric polarization is a consequence of the fact when an electric field acts on a molecule, its positive charges (nuclei) are displaced along the field while the negative charges (electron) in a direction opposite to that of the field. The displacement of electric charges results in the formation of electric dipole moment in atoms, ion or molecules of the material. The three important types of polarization are

(i) Electronic Polarization
(ii) Ionic Polarization
(iii) Orientational Polarization.

Electronic Polarization:-



classical model of an atom.

The type of polarization has be explained with the help of rare gases atoms, in which it is assumed that the interaction among the atoms is negligible. Here the nucleus of charge