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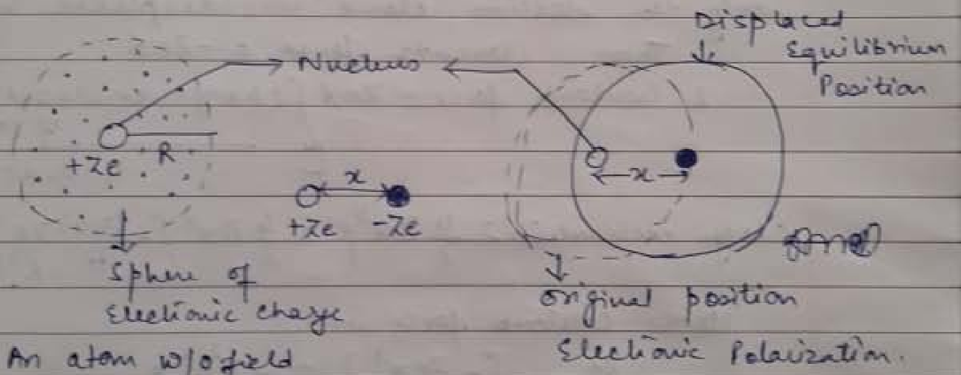
B.Sc (PS) Computer Science VI Sem
Dielectrics

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

Ze is surrounded by an electronic cloud of charge $-Ze$ distributed in a sphere of radius R. Thus charge density, ρ is given by

$$\rho = -\frac{Ze}{\frac{4}{3}\pi R^3} = -\frac{3}{4}\frac{Ze}{\pi R^3} \quad \text{—— (1)}$$

When this system is subjected to an external field of intensity E, the nucleus and the electron experience lorentz force of magnitude ZeE in opposite directions. Therefore the nucleus and electron cloud are pulled apart. As they pulled apart, a coulomb force develops between them, which tends to counter the displacement and the actual magnitude is very small, even (10^{-17}m) for a very high field (30KV/m). Let the small displacement be x. To calculate the induced dipole moment in the atomic model it is firstly assumed that only the electron cloud is displaced by the field.

Thus lorentz force $= -ZeE$

& coulomb force $= Ze \times \left[\frac{\text{charge enclosed in the sphere of radius } x}{4\pi\epsilon_0 x^2}\right]$

Charge enclosed is $= \frac{4}{3}\pi x^3 \rho = \frac{4}{3}\pi x^3 \left[-\frac{(3/4)}{\pi}\frac{Ze}{R^3}\right] = -\frac{Zex^3}{R^3}$

Hence coulomb force is

$$\frac{Ze}{4\pi\epsilon_0 x^2}\left[-\frac{Zex^3}{R^3}\right] = -\frac{Z^2e^2x}{4\pi\epsilon_0 R^3} \quad \text{—— (2)}$$

In the equilibrium position, the two forces are equal

$$-ZeE = \frac{-Z^2e^2x}{4\pi\epsilon_0 R^3}$$

$$E = \frac{Zex}{4\pi\epsilon_0 R^3}$$

$$x = \frac{4\pi\epsilon_0 R^3 E}{Ze} \quad \text{—— (3)}$$

The displacement of the electron cloud is proportional to the applied field E.

Thus the two electric charges +Ze and -Ze are now displaced by a distance x under the field constitute an electric dipole and has induced electric dipole moment given by

$$P_e = Zex = Ze\frac{4\pi\epsilon_0 R^3 E}{Ze}$$

$$P_e = 4\pi\epsilon_0 R^3 E$$

$$P_e \propto E$$

$$P_e = \alpha_e E \qquad \text{— (4)}$$

$$\alpha_e = 4\pi\epsilon_0 R^3 \qquad \text{— (5)}$$

is called electronic Polarizability. Thus the induced electronic dipole moment is proportional to the applied field. The dipole moment per unit volume is called electronic Polarization.

i.e $\vec{P}_e = N\vec{p}_e = N\alpha_e\vec{E}$

Where N is the number of atoms/m^3

But $\vec{P}_e = \epsilon_0(\epsilon_r - 1)\vec{E}$

$\therefore \vec{E}\epsilon_0(\epsilon_r - 1) = N\alpha_e\vec{E}$

$$\epsilon_r - 1 = \frac{N\alpha_e}{\epsilon_0} \qquad \text{— (6)}$$

Where ϵ_r is the dielectric Constant of material.

Atomic or Ionic Polarization:-

When an Electric field is applied to an ionic Crystal, the polarization that arises due to the displacement of the positive ions away from the field and the displacement of the negative ions towards the field is known as Atomic or Ionic Polarization. E.g NaCl, KBr, KCl and LiBr.

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When an electric field is applied, there is a displacement of the positive and negative ions which produces an induced dipole moment P_i and is proportional to the applied field and an ionic polarizability α_i i.e

$$P_i = \alpha_i E$$

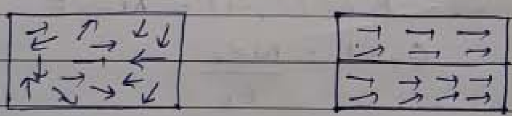
for N no. of dipoles per unit volume is given by

$$\vec{P_i} = N\alpha_i \vec{E}$$

Typically $\alpha_i = 0.1\alpha_e$.

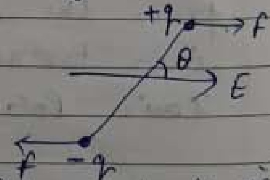
Dipolar or orientation Polarization :- α_d

The dipolar or orientation polarization is produced only in the case of polar molecules such as H_2O, HCl and nitrobenzene. When an electric field is applied to a polar molecular, the dipoles experience a torque and try to allign parallel to the applied field, which results in a rotation of the dipoles, as shown in fig. below.



(a) Random orientation of dipoles in the absence of Electric field (b) The dipoles try to align parallel to the applied field.

Assume a dipole system placed in a uniform electric field, out of which consider a dipole as shown in fig. Force exerted by the field on the positive and negative charges of the dipole is equal but acts in opposite direction.



Polar molecule in an electric field.

A torque exerted by the field on the dipole having a dipole moment $\vec{p}$ is given by

$$\vec{\tau} = \vec{p} \times \vec{E}$$

The magnitude of the torque is $pE\sin\theta$, where θ is the angle b/w the direction of the field and the moment, and the direction of the torque is such that it tends to turn the dipole into the direction of the field i.e to reduce θ. The Potential energy of the dipole in the field given by

$$U = -\vec{p}\cdot\vec{E} = -pE\cos\theta$$

Energy of the dipole is minimum ($= -pE$) when $\theta = 0$ i.e dipole are aligned parallel to the field and is maximum ($= pE$) when $\theta = 180°$ i.e when the dipole is antiparallel to the field.

Despite the minimum energy condition of $\theta = 0$, all the dipoles do not point in the direction of the field because of thermal agitation. A dipole of moment p making an angle θ with the direction of the field contributes to the polarization a component $p\cos\theta (= p_x)$. According to the Boltzmann statistics, the probability of finding a dipole within the solid angle θ and $\theta + d\theta$ or ($d\Omega$) is proportional to the Boltzmann factor

$$f(\theta) = \exp\left(\frac{-U}{k_B T}\right) = \exp\left(\frac{pE\cos\theta}{k_B T}\right) \quad \text{— (1)}$$

Therefore, the average moment contribution per dipole P_d lying within the solid angle can be determined by integrating over all angles from parallel alignment $\theta = 0$, to antiparallel alignment $\theta = \pi$, so that

$$P_d = \frac{\int_0^\pi p_x f(\theta)\, d\Omega}{\int_0^\pi f(\theta)\, d\Omega} \quad \text{— (2)}$$