DIELECTRICS

1) What is meant by dielectric ? Explain polar and non-polar dielectrics.

Dielectrics constitute a very important group of electrical engineering materials. Dielectrics are electrically non-conducting materials such as glass, ceramics, polymers and paper. When their role is to provide electrical insulation, they are called as insulators. When they are placed in electric fields, they modify the electric fields and they themselves get polarized as a result of which they act as stores of electric charges. When charge storage is the main function, the non-conducting materials are called dielectrics. The resistivity of an ideal dielectric should be infinity. However, practical dielectrics conduct electric current to a negligible extent. Under high voltage bias, they allow a very little current in the range 10^{-6} to 10^{-14} A. Dielectrics generally are non-metallic. They have negative temperature coefficient of resistance. They have high resistivities ranging from 10^{10} to 10^{20} Ω m.

Depending upon the molecular structure, dielectric materials are broadly classified into two types; they are polar dielectrics and non-polar dielectrics.
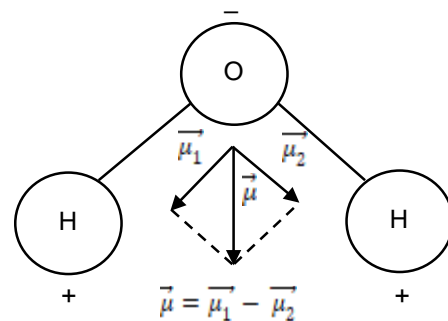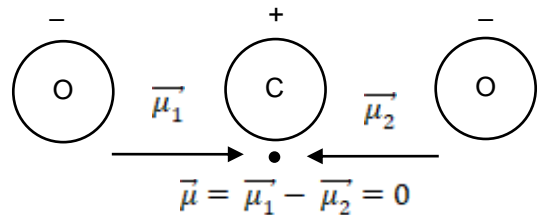
(1) NON-POLAR DIELECTRICS

In the molecules (or atoms) of some dielectric materials, which are usually diatomic, the effective centre of the negative charge distribution coincides

with the effective center of the positive charges thus neutralizing each other's effect. In the absence of external field, the net dipole moment is zero and have symmetrical structure. Such materials are called non-polar dielectrics.

Ex : H_2, N_2, O_2, CO_2, C_6H_6 etc.

(2) POLAR DIELECTRICS

Generally, polyatomic substances contain molecules in which the effective centers of the negative and positive charges do not coincide with each other even in the absence of the electric field and hence every molecule possesses a dipole moment and have unsymmetrical structure. But, these molecules are oriented randomly and hence, the net dipole moment is zero in the absence of the

field. Such materials are called polar dielectrics.

Eg: H_2O, CO_2, N_2O, NH_3 etc.

2) Explain the following.

i) electric diploe   **ii) electric dipole moment**

iii) polarization   **iv) electric flux density**

(i) Electric dipole :

  A pair of equal and opposite charges whose distance of separation is very small, is called an electric dipole.

(ii) Electric Dipole moment $\overline{\mu}$:

  The dipole moment is defined as the product of the magnitude of one of the charges and the distance of their separation. It is denoted by $\overline{\mu}$.

  $\overline{\mu} = q\ \overline{r}$, where q is magnitude of the charge and r is the distance between the charges. This dipole moment is a vector quantity and its direction is always from negative to positive charge. Its unit is debye.

$$1 \text{ debye} = 3.33 \times 10^{-30} \text{ coulomb-meter}$$

If each particle (atom or molecule) of a substance possesses a dipole moment, the net dipole moment of the sample is given by, $\overline{\mu} = \sum^{i} q_i\ r_i$

(iii) Polarization $\overline{P}$:

  When a dielectric is placed in an electric field, the positive charges in the dielectric are displaced in the direction of the field, while the negative charges are displaced in the opposite direction. This displacement of charges produces local dipoles throughout the dielectric. This process of producing local dipoles by an electric field is called Polarization (P) in dielectrics. Polarization can take place in both polar and non-polar dielectrics.

The induced dipole moment per unit volume of the dielectric is called the polarization, denoted by $\overline{P}$. It is a vector quantity whose direction is along the direction of the applied electric field (pointing from negative to positive charge in the dielectric). Magnitude of polarization is equal to the induced charge density.

Atomic point of view of polarization of a dielectric
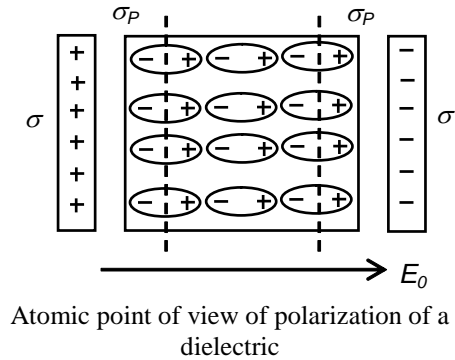
If +q and –q are the charges induced on the faces of a dielectric slab of thickness t kept between the plates of a capacitor, then total dipole moment of the bulk dielectric = charge x distance of separation = q x t.

If A is the surface area of the face, then the volume of the slab = A x t.

$$\text{Magnitude of polarization} = \frac{\text{Dipole moment}}{\text{Volume}} = \frac{q\,t}{A\,t} = \frac{q}{A}.$$

The magnitude of polarization is equal to the induced charge density σ_P. The unit of polarization is coulomb / metre^2.

(iv) Electric flux density (electric displacement vector) $\overline{D}$:

The electric flux density is the number of flux lines crossing a surface normal to the lines, divided by the surface area. $D \propto E$ or $D = \epsilon E = \epsilon_0\,\epsilon_r\,E$, where ϵ is the permittivity of medium, $\epsilon = \epsilon_0\,\epsilon_r$, ϵ_0 is the permittivity of free space = 8.854 X 10^{-12} farad/metre and ϵ_r is the relative permittivity of medium.

We know the expression for electric field intensity is,

$$E = \frac{q}{4\,\pi\,\varepsilon_0\,r^2}$$

$D = \frac{q\,\epsilon}{4\pi\,r^2} = \frac{q}{4\pi\,r^2} = \frac{q}{A}$, where A is area of the dielectric. The surface charge per unit area is called electric flux density. It is a vector quantity, its direction is along the direction of the electric field intensity. It has the units coulomb per square metre.

The electric displacement or electric induction D is an auxiliary vector which is very useful quantity for analyzing electro static fields in the presence of dielectric. Its magnitude is equal to the surface density of free charge σ.

Thus $D = \sigma$

This quantity D is similar to the magnetic induction B in the Magnetism.

3) Explain dielectric constant, dielectric susceptibility and polarizability.

Dielectric constant (Relative permittivity) ε_r

The dielectric constant or relative permittivity of a medium can be defined as the ratio between the permittivity of a medium to the permittivity of the free space.

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$$

The dielectric constant ε_r is dimensionless quantity and its value is unity for vacuum which is lowest value it can possess. It is independent of the size or shape of the dielectric. ε_r is usually measured by comparing the capacitance of the capacitor with the dielectric to the capacitance of the same capacitor without the dielectric. $\varepsilon_r = \dfrac{C}{C_0}$. The capacitance C_0 of a parallel plate capacitor with air or vacuum as the medium is given by $C_0 = \dfrac{\varepsilon_0 A}{d}$, where $\varepsilon_0 = 8.85 \times 10^{-12}$ farad/metre is the permittivity of free space, A is the plate area, and d is the separation between the plates. The capacitance C with the dielectric present is $C = \dfrac{\varepsilon_0 \varepsilon_r A}{d}$.

ε_r is a physical quantity which depends on the structure of the atoms of which the material is composed of. It has a marked frequency dependence when the material is subjected to an alternating field at which time it becomes a complex quantity.

It is a measure of the extent of electric stress absorbed by the material when subjected to an external electric field. It is a measure of the polarization in the dielectric material.

Dielectric susceptibility :

Polarization P is a vector and is defined as the total dipole moment per unit volume of the dielectric. If μ is the average dipole moment in a unit volume and N is the number of molecules per unit volume, then the dielectric polarization P can be written as $P = N\mu$

$$P = N\alpha E$$

Also Polarization P is directly proportional to the intensity of the electric field E and is in the same direction of E.

Thus $P = \epsilon_0 \chi E$, where the constant χ is called the dielectric susceptibility and is a characteristic property of every dielectric. χ characterizes the ease with which a dielectric material can be influenced by an electric field. It is the polarization per unit electric field.

$$\chi = \frac{P}{\epsilon_0 E}$$

Polarizability :

The dipole moment induced in an atom is proportional to the electric field.

$\mu \, \alpha \, E \; or \; \mu = \alpha E$, where α is the constant of proportionality called polarizability. The induced dipole moment per unit electric field is called polarizability. If there are *N* molecules per unit volume, the polarization of the solid, $P = N \, \mu = N \, \alpha \, E$.

.   It is important to note that polarizability is not a bulk property of the material but the property of an individual atom or molecule. It is considered as an important microscopic electrical parameter of a dielectric.

4) With usual notation, show that $P = \epsilon_0(\epsilon_r - 1)E$.

Consider a parallel plate capacitor with an electric field E_0 between the plates. If σ is the charge per unit area on the plates, then from Gauss's law,

$$E_0 = \frac{\sigma}{\epsilon_0} \qquad \text{----------- (1)}$$

Let the given dielectric slab be placed between the two plates. Due to polarization charges appear on the two faces of the slab and establish another field within the dielectric. Let this field be E_1. The direction of E_1 will be opposite to that of E_0
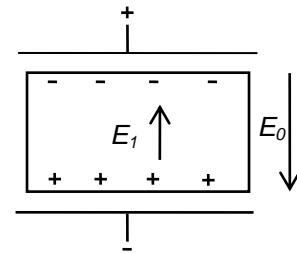

Fig. 1

The resultant field E in the material is $E = E_0 - E_1$ -------- (2)

If σ_P is the charge per unit area on the dielectric surfaces, then from equation (1), one can write,

$$E_1 = \frac{\sigma_P}{\epsilon_0} \qquad \text{----------- (3)}$$

From equations (1), (2) and (3),

$$\epsilon_0 E = \sigma - \sigma_P \quad \text{----------- (4)}$$

The magnitude of polarization P is the induced charge per unit area, $P = \sigma_P$. The electric field strength E and electric flux density D are related by

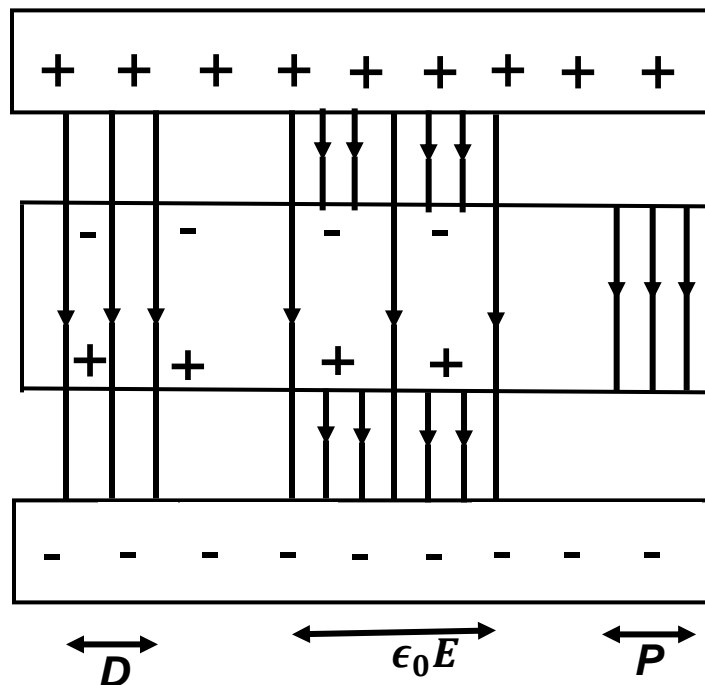$$D = \epsilon_0 \epsilon_r E \text{ and } D = \sigma$$

Equation (4) can be written as $\epsilon_0 E = D - P \Rightarrow D = \epsilon_0 E + P \Rightarrow D = \frac{\epsilon}{\epsilon_r} E + P$

This equation relates the electric displacement vector $\bar{D}$ and the dielectric constant ϵ_r to polarization vector $\bar{P}$.

Consider the equation, $\epsilon_0 E = D - P$

$$P = \epsilon_0 \epsilon_r E - \epsilon_0 E$$

$P = \epsilon_0 (\epsilon_r - 1) E \Rightarrow P = \epsilon_0 \chi E$, where $\chi = (\epsilon_r - 1)$ is the dielectric susceptibility of the material. The equation $\bar{P} = \epsilon_0 (\epsilon_r - 1) \bar{E}$ is the equation for polarization vector.

From the definitions of *E*, *P* and *D*, we derive the following information.

(1) *D* is connected with free charges only. We can represent the vector field *D* by lines of *D*, just as we represent the field of *E* by lines of force. Figure shows that the lines of *D* begin and end on the free charges.

(2) *P* is connected with the Polarization charge only. Figure shows that the lines of *P* field begin and on the polarization charges.

(3) *E* is connected with all charges that are actually present, whether free or polarization. The lines of *E* reflect the presence of both kinds of charges. The units of *P* and *D* (Coulomb/m^2) differ from those of *E* (Newton/Coulomb).

5) Name the four types of polarization mechanisms that can take place in the presence of an electric field in dielectric materials.

When a dielectric material is placed inside a dc electric field, polarization is due to four types of processes.

1) electronic polarization

2) ionic polarization

3) orientation polarization and

4) space charge polarization

6) What is electronic polarization ?

The displacement of the positively charged nucleus and the electrons of an atom in opposite directions on application of an electric field is called electronic polarization.

7) Describe the phenomenon of electronic polarization.

This type of polarization is present in all dielectrics in any state of aggregation. It results from the displacement of the electron clouds atoms,

Sphere of electronic charge
Nucleus
Displaced equilibrium position
Original position
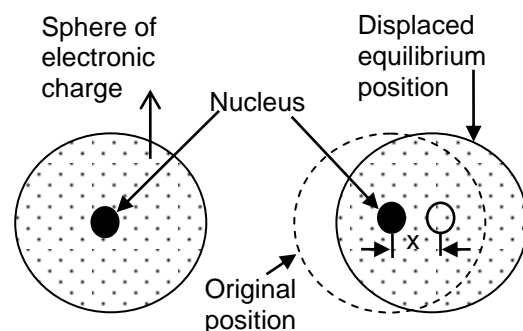
molecules and ions with respect to the heavy fixed nuclei to a distance that is less than the dimensions of the atoms, molecules or ions in the presence of an electric field. This is shown in the figure.

When the field is switched on, the Lorentz force will tend to separate the nucleus and the electron cloud from their equilibrium positions until the restoring force due to Coulomb attraction balances the process. Finally, a new equilibrium will be reached when these two forces are equal and opposite. Hence, the opposite charges are displaced from each other with a distance between them. The atom acts as a dipole and acquires dipole moment

Electronic polarization P_e sets in over a very short period of time of the order of 10^{-14} to 10^{-15} second. It is independent of temperature. P_e is given by $P_e = N \, \alpha_e E$, where α_e is the electronic polarizability and N is the number of atoms per m³. The contribution of P_e to the dielectric constant ϵ_r is given by

$$\epsilon_r = 1 + \chi = 1 + \frac{P_e}{\epsilon_0 E} = 1 + \frac{N\alpha_e E}{\epsilon_0 E}$$

$$\epsilon_r = 1 + \frac{N\alpha_e}{\epsilon_0}$$

The above expression indicates the dielectric constant due to electronic polarization alone and thus gives the dielectric constant of a nonpolar gaseous dielectric. It shows that the dielectric constant of a nonpolar gas depends on the polarizability of a molecule and the number of molecules in a unit volume of the dielectric. In case of a monoatomic gas it is found that the electronic polarization is given by $\alpha_e = 4\pi \, \epsilon_0 \, R^3$.

$\epsilon_r = 1 + 4\pi \, NR^3$, where R represents the radius of the atom.

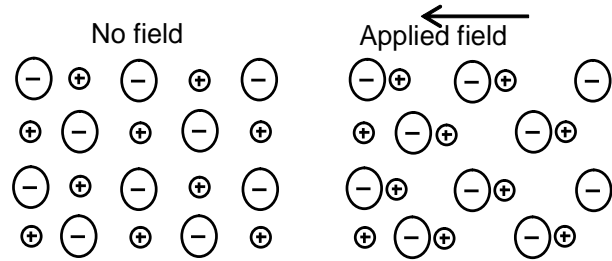**7) Define ionic polarization ?**

When an ionic solid is placed inside an electric field, the cations and anions are displaced in opposite directions. This is called ionic polarization.

8) Explain ionic polarization.

Ionic crystalline dielectrics like NaCl and CsCl exhibit ionic polarization. It is bought about by the elastic displacement of the positive ions of the lattice along the field direction and of the negative ions in the opposite direction. Consider NaCl crystal as an example. An NaCl molecule consists of Na+ ions bound to Cl− ions through ionic

No field   Applied field

bond. Because of an inherent interatomic distance, the molecule exhibits an intrinsic dipole moment. When an electric field is applied to the molecule, the Na+ and Cl− ions are displaced in opposite directions until the ionic bonding forces stop the process. The dipole moment of the molecule consequently increases. When the field direction is reversed the ions move closer and again the dipole moment undergoes a change. The induced dipole moment is proportional to the applied field and is given by $\mu_i = \alpha_i E$, where α_i is the ionic polarizability. The phenomenon of ionic polarization is shown in the figure. The ions also experience electronic polarization. For most materials, α_i is less than α_e. Typically $\alpha_i = \frac{1}{10} \alpha_e$. The ionic polarization is given by $P_i = N \alpha_i E$. It takes about 10^{-11} to 10^{-14} s to build up, and is not influenced by temperature.

Assuming that there are one cation and one anion in the unit cell of that ionic crystal, one gets

$$\alpha_i = \frac{e^2}{\omega_0^2}(\frac{1}{M} + \frac{1}{m})$$

Thus the ionic polarizability α_i is inversely proportional to the square of the natural frequency of the ionic molecule and to its reduced mass where the reduced mass is mathematically equal to $(\frac{1}{M} + \frac{1}{m})^{-1}$. In the above equation, e is the charge of the ions, m is equal to the mass of the positive ion, ω_0 being the angular frequency of the molecule and M is equal to the mass of the negative ion.

9) Define orientation polarization ?

When an electric field is applied on molecules which possess permanent dipole moment, they tend to align themselves in the direction of applied field. The polarization due to such alignment is called orientation polarization.

10) Describe the phenomenon of orientation polarization.

Certain substances, called polar substances, consist of molecules that have permanent dipoles even in the absence of external field. But, all the dipoles are oriented randomly in the absence of external field, such that the net dipole moment is zero.

No field   Applied field **E**
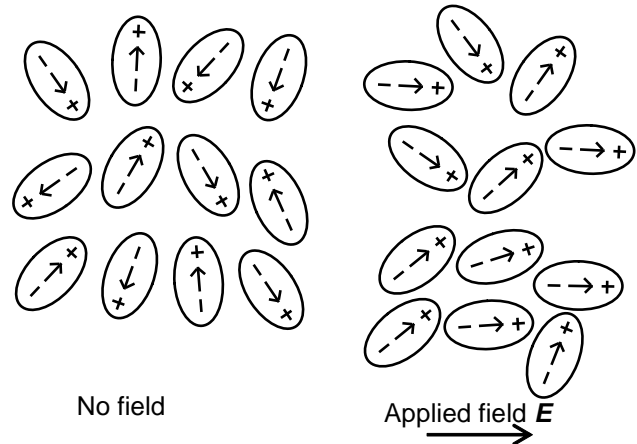
However, when they are placed in external field, molecular dipoles align in the field direction, resulting in a net dipole moment. This kind of polarization is called orientation polarization or dipolar polarization.

In electronic and ionic polarizations, the restoring forces due to coulomb attractions balance the electric forces due to the external electric field. No such restoring forces exist in dipole polarization. However, thermal agitation to some extent restricts the dipole orientation making the complete alignment impossible. The dipoles can rotate only through small angles as the figure illustrates. Even in fluids, where the molecules are free to rotate, complete alignment is not achieved because of the randomizing effect of temperature. However, estimates indicate that if one molecular dipole in 10^5 completely aligns with the field, it is enough to produce orientation polarization comparable to electronic polarization. The orientation is therefore strongly temperature dependent. In solids, the lattice forces highly restrict the rotation of polar molecules resulting in a greater reduction in their contribution to orientation polarization. Because of this reason, the dielectric constant of water is as high as 80, while that of solid ice is only about 10.

The process of orientation polarization involves rotation of molecules. As such it takes relatively longer time compared to other two polarizations. The build up time is of the order of 10^{-10} s or more. The orientation polarization is given by $P_0 = N\alpha_0 E$, where α_0 is the orientation polarizability. α_0 is expressed by the relation $\alpha_0 = \frac{\mu^2}{3\,k\,T}$. Therefore $P_0 = \frac{N\,\mu^2 E}{3\,k\,T}$ which is known as the Debye's law. We see from this equation that P_0 is inversely proportional to the absolute temperature of the material and proportional to the square of the permanent dipole moment.

11) Discuss the dependence of electronic, ionic and orientation polarizations on temperature.

In a material which can experience all forms of polarization, the total polarizability is equal to the sum of the electronic, ionic and orientation polarizations.

$$\alpha = \alpha_e + \alpha_i + \alpha_o = \alpha_e + \alpha_i + \frac{\mu^2}{3\,k\,T}$$

The total polarization P may be expressed as $P = P_e + P_i + P_o$

The total polarization of a polar dielectric may be expressed as $P = N\left[\alpha_e + \alpha_i + \frac{\mu^2}{3\,k\,T}\right] E$

The dielectric constant of a polar gaseous dielectric may be expressed as

$$\frac{P}{E} = \epsilon_0\,(\epsilon_r - 1) = N\left[\alpha_e + \alpha_i + \frac{\mu^2}{3\,k\,T}\right]$$

It is observed that if the dielectric constant ϵ_r is plotted as a function $1/T$, the equation

$\epsilon_0\,(\epsilon_r - 1) = N\left[\alpha_e + \alpha_i + \frac{\mu^2}{3\,k\,T}\right]$ predicts the result to be a straight line. The slope of this line is determined by μ^2, the intercept with the axis $1/T = 0$ provides a measure for $(\alpha_e + \alpha_i)$. From the results obtained one may derive certain conclusions with regard to the structure of the molecules. Dielectric constant measurements have been used a great deal as a tool for investigating molecular structure.

α_0 is inversely proportional to the temperature. α_e and α_i are independent of temperature.

It is possible that one or more forms of polarization to be either absent or negligible in magnitude relative to the others. For example, orientation polarization does not exist in nonpolar dielectrics. Similarly, covalently bonded dielectrics do not contribute to ionic polarization. Electronic polarization is present in all dielectrics but is negligible compared to orientation polarization in polar dielectrics.
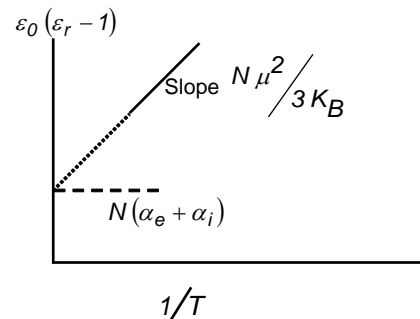
12) Derive an expression for the internal field in a dielectric material ?

The total electric field which a dipole experiences in a medium is called the local field or internal field or Lorentz field denoted by E_L. This is different from externally applied field. If we consider a dipole, in addition to the external field, the remaining dipoles impose an internal electric field on the molecule under consideration. Therefore, an effective field exists on every molecule, which is equal to the sum of the external field and the field due to all the other dipoles around it. This total field is known as internal field or local field or Lorentz field, E_L .

This was evaluated by Lorentz. For this, let us consider a dielectric which is placed between two electrodes as shown in the figure.
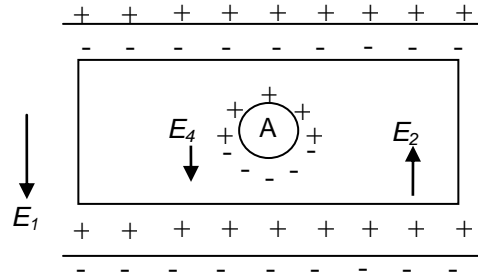
Let there be an imaginary spherical cavity around the atom A inside the dielectric. It is also assumed that the radius of the cavity is large compared to the radius of the atom. The internal field at the atom site A can be considered to be made up of the following four components namely E_1, E_2, E_3 and E_4.

The total electric field acting on the molecular dipole which is at the center of the cavity is given by,

$E_L = E_1 + E_2 + E_3 + E_4$, where

E_1 is the field intensity at A due to charges on the plates of capacitor (i.e., field without dielectric). We know that

$$D = \sigma \ \& \ D = P + \epsilon_0 E$$

$$E_1 = \frac{\sigma}{\epsilon_0} = \frac{D}{\epsilon_0} = \frac{P + \epsilon_0 E}{\epsilon_0} \Rightarrow E_1 = E + \frac{P}{\epsilon_0}$$

E_2 is the field intensity at A due to the charge density induced on the two sides of the dielectric. This field opposes the original field and is called depolarization field.

$$E_2 = \frac{-\sigma_P}{\epsilon_0} \ \& \ \sigma_P = P \Rightarrow E_2 = \frac{-P}{\epsilon_0}$$

E_3 is the field intensity at A due to all the dipoles inside the spherical cavity. This field depends on symmetry of the crystal and for a cubic structure the electric field E_3 =0.

To calculate E_4, let us imagine that the dielectric is removed from the sphere. For the actual pattern of the electric field not to be distorted, a surface electric charge should be placed on the spherical surface. The enlarged view of the cavity is shown in figure. If dA is the surface area of the sphere of radius r lying between θ and $\theta + d\theta$ where θ is the angle between radius vector r and the direction of E.
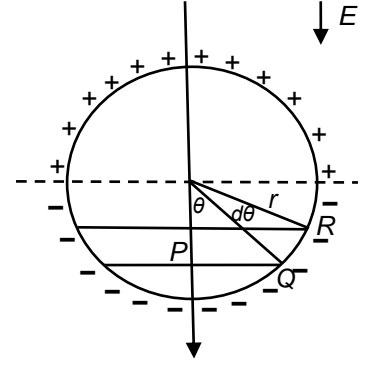
$$dA = 2\,\pi\,(PQ)(QR)$$

$$PQ = r\sin\theta \ \& \ QR = r\,d\theta \ \Rightarrow dA = 2\pi\,(r\sin\theta)\,(r\,d\theta) \Rightarrow dA = 2\,\pi\,r^2\sin\theta\,d\theta$$

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

$$dq = P\cos\theta\,dA$$

This charge will produce electric field intensity dE_4 at the center of the sphere.

$$dE_4 = \frac{dq}{4\,\pi\,\epsilon_0\,r^2} = \frac{P}{4\,\pi\,\epsilon_0\,r^2}\cos\theta\,dA$$

This electric field can be resolved into two components, one component $dE_4\cos\theta$ parallel to the direction of E and the other $dE_4\sin\theta$ perpendicular to the direction of E.

$$dE_4\cos\theta = \frac{P}{4\,\pi\,\epsilon_0\,r^2}\cos^2\theta\,dA \ \text{ and } dE_4\sin\theta = \frac{P}{4\,\pi\,\epsilon_0\,r^2}\cos\theta\sin\theta\,dA$$

It is obvious that the perpendicular components of the upper and lower half of the sphere cancel each other and only the parallel components contribute to the total intensity E_4. E_4 is obtained by integrating dE_4 over the whole surface area of the sphere.

$$E_4 = \int_0^\pi dE_4\cos\theta\,dA = \frac{P}{4\,\pi\,\epsilon_0\,r^2}\int_0^\pi \cos^2\theta\,dA = \frac{P}{4\,\pi\,\epsilon_0\,r^2}\int_0^\pi \cos^2\theta\,(2\pi\,r^2\sin\theta\,d\theta)$$

$$E_4 = \frac{P}{2\,\epsilon_0}\int_0^\pi \cos^2\theta\sin\theta\,d\theta$$

Let $\cos\theta = x$ and therefore $-\sin\theta = dx$

$$E_4 = -\frac{P}{2\,\epsilon_0} \int_{+1}^{-1} x^2 \, dx = -\frac{P}{2\,\epsilon_0} \left[\frac{x^3}{3}\right]_{+1}^{-1} = \frac{2P}{6\,\epsilon_0}$$

$$\therefore \; E_4 = \frac{P}{3\,\epsilon_0}$$

Hence, local field is, $E_L = E_1 + E_2 + E_3 + E_4$

$$E_L = E + \frac{P}{\epsilon_0} - \frac{P}{\epsilon_0} + 0 + \frac{P}{3\,\epsilon_0}$$

$$E_L = E + \frac{P}{3\,\epsilon_0}$$

The above equation is known as Lorentz field or local field. Here, it should be observed that the local field is greater than the electric field applied.

13) Derive Claussius-Mosotti relation in dielectrics subjected to static fields ?

Let us consider the elemental dielectrics having cubic structure, like Ge, Si, and C etc. Since there are no ions and permanent dipoles in these materials, ionic polarizability $\alpha_i = 0$ and oriental polarizability $\alpha_o = 0$. They exhibit only electronic polarizability α_e

$P = N\,\alpha_e\,E_L$ [since $\mu \propto E$ or $\mu = \alpha_e E$ and $P = N\,\mu \; \therefore \mathrm{P} = \mathrm{N}\,\alpha_e\,\mathrm{E}$]

Substituting the Lorentz form for local field E_L we get

$$P = N\,\alpha_e \left(E + \frac{P}{3\,\epsilon_0}\right) \Rightarrow P = N\alpha_e E + \frac{N\,\alpha_e\,P}{3\,\epsilon_0}$$

$$P - \frac{N\,\alpha_e\,P}{3\,\epsilon_0} = N\alpha_e E \Rightarrow P\left(1 - \frac{N\,\alpha_e}{3\,\epsilon_0}\right) = N\alpha_e E \Rightarrow P = \frac{N\alpha_e E}{1 - \frac{N\alpha_e}{3\,\epsilon_0}}$$

We Know that, $P = \epsilon_0 \,(\epsilon_r - 1)\,E$

$$\epsilon_0 \,(\epsilon_r - 1)\,E = \frac{N\alpha_e E}{1 - \frac{N\alpha_e}{3\,\epsilon_0}} \Rightarrow 1 - \frac{N\alpha_e}{3\,\epsilon_0} = \frac{N\alpha_e}{\epsilon_0\,(\epsilon_r - 1)}$$

$$1 = \frac{N\alpha_e}{3\,\epsilon_0} + \frac{N\alpha_e}{\epsilon_0\,(\epsilon_r - 1)} = \frac{N\alpha_e}{\epsilon_0} \left\{\frac{1}{3} + \frac{1}{(\epsilon_r - 1)}\right\} = \frac{N\alpha_e}{3\,\epsilon_0} \frac{(\epsilon_r + 2)}{(\epsilon_r - 1)}$$

$$\frac{(\epsilon_r - 1)}{(\epsilon_r + 2)} = \frac{N\alpha_e}{3\,\epsilon_0}$$

where N is the number of molecules per unit volume. The above equation is known as Clausius-Mosotti equation. Using this relation one can determine the value of α_e, knowing the value of ϵ_r of the medium. Along with elemental dielectrics this equation is more suitable for gases and then for liquids. For crystalline solids, the interaction of the dipoles with each other produce polarization which are more complicated than those of our simple model and this equation is not valid.

14) Give a schematic sketch of variation of the total polarizability of a dielectric as a function of the frequency and explain the relevant frequency ranges.

On application of the electric field, a polarization process occurs as a function of time. The Polarization $P(t)$ as a function of time t is given by

$$P(t) = P_0 \left[1 - exp\left(\frac{-t}{t_\tau}\right) \right]$$

where P_0 is the maximum polarization attained on prolonged application of a static field and t_τ is the relaxation time for the particular polarization process. The relaxation time t_τ is a measure of the time scale of a polarization process. It is the time taken for a polarization process to reach 0.63 of the maximum value. This varies widely for different polarization processes.

Electronic polarization: Electronic polarization is extremely rapid. Even when the frequency of the applied voltage is very high in the optical range ($\sim 10^{15}$ Hz), electronic polarization occurs during every cycle of the applied voltage.

Ionic polarization: Ionic polarization is due to the displacement of ions over a small distance due to the applied field. Since ions are heavier than electron cloud, the time taken for displacement is larger. The frequency with which ions are displaced is of the same order as the lattice vibration frequency ($\sim 10^{13}$ Hz). This means that for optical frequency the ions do not respond, as the time required for lattice
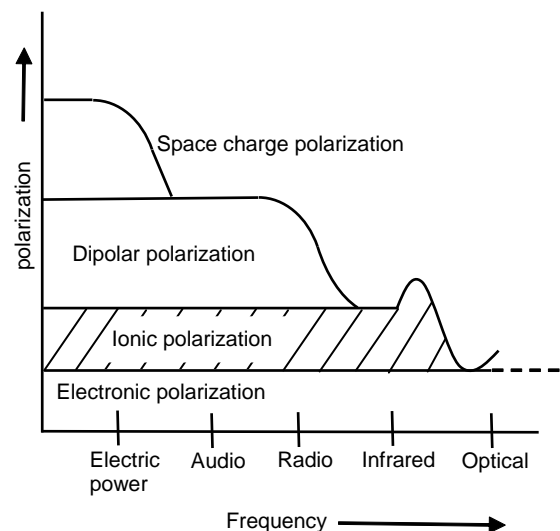
vibrations is nearly 100 times larger than the period of applied voltage at optical frequency. Hence at optical frequencies, there is no ionic polarization. If the frequency of the applied voltage is less than 10^{13} Hz, the ions respond. Hence at 10^{13} Hz we have both electronic polarization and ionic polarization responding.

Orientation polarization: Orientation polarization is even slower than ionic polarization. The relaxation time for orientation polarization in a liquid is less than that in a solid. For example the relaxation time for orientation polarization is 10^{-10}s in liquid propyl alcohol while it is 3×10^{-6} sec in solid ice. Orientation Polarization occurs when the frequency of the applied voltage is in the audio range.

Space charge Polarization: Space charge polarization is the slowest process, as it involves the diffusion of ions over several inter atomic distances. The relaxation time for this process is related to the frequency of successful jumps of ions under the influence of the applied field, a typical value being 10^2 Hz. Correspondingly, space charge polarization occurs at power frequencies (50-60 Hz). The figure illustrates all four types of polarization at different frequency ranges. At optical frequencies (($\sim 10^{15}$ Hz) electronic polarization alone is present. At $\sim 10^{13}$ Hz range ionic polarization occurs in addition to electronic polarization. At 10^6 to 10^{10} Hz range contribution due to orientation polarization gets added while at 10^2 Hz range space charge polarization also contributes.

15) Mention applications of dielectric materials.

1) Dielectrics are very widely used as insulating materials.

a) Electrical conductors made of aluminium or copper which are used for electric wiring are insulated with a outer jacket of plastic or rubber.

b) In heater coils, ceramic beads are used to avoid short circuiting as well as to insulate the outer body from electric current.

c) In electric iron, mica or asbestos insulation is provided to prevent the flow of electric current to the outer body of the iron.

d) In transformers as well as in motor and generator windings varnished cotton is used as insulator.

e) In electricity distribution lines, porcelain structures are used as insulators between points of different potential.

2) Another important application of dielectric material is their use as energy storage capacitors. Depending on the application and type of dielectric used, the capacitors may be grouped into a) capacitors with vacuum, air or inert gas as dielectric, b) capacitors with mineral oil as dielectric, c) capacitors with solid as dielectric and d) capacitors with both solid and liquid as dielectric.

3) Dielectric heating : The insulating materials can be efficiently heated up by subjecting them to a high voltage of suitable frequency, namely the frequency at which dielectric loss is maximum. The dielectric loss manifests in the form of heat. Cooking in microwave oven is one of the popular dielectric heating.

4) Dielectric resonators are used to provide a frequency reference in an oscillator circuit. An unshielded dielectric resonator can be used as a dielectric resonator antenna.

16) Define space-charge polarization ?

There is also a fourth type called space-charge polarization which is found at the interfaces in multiphase dielectrics such as ferrites and semiconductors. But because of its relative insignificance, it is commonly ignored

When multiphase dielectrics such as ferrites and semiconductors are placed in an electric field, the ions diffuse over appreciable distances giving rise to redistribution of charges. Such charges accumulate at the electrodes or at the interfaces in the multiphase material. This process is called space-charge polarization.