DEPARTMENT OF PHYSICS AND NANOTECHNOLOGY
SRM INSTITUTE OF SCIENCE AND TECHNOLOGY

18PYB101J-Electromagnetic Theory, Quantum Mechanics, Waves and Optics

Module I Lecture-14

Types of Polarization mechanisms, Frequency and Temperature Dependence of the polarization

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Various Polarization mechanisms in Dielectrics

Dielectric polarization is the displacement of charged particles under the action of the external electric field. Several microscopic mechanisms are responsible for electric polarization.

➢ Four types of microscopic polarization mechanisms.

- ➢ Electronic polarization
- ➢ Ionic polarization
- ➢ Orientation polarization and
- ➢ Space-charge polarization.

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i. Electronic Polarization

- Electronic Polarization occurs due to the displacement of positively charged nucleus and negatively charged electrons in opposite directions, when an external electric field is applied, and thereby a dipole moment is created in the dielectric.

- $\therefore$ The induced dipole moment $\mu = \alpha_e E$
- where α_e = electronic polarizability.
- Monoatomic gases exhibit this kind of polarization, Electronic polarizability is proportional to the volume of the atoms and is independent of temperature.
- The electronic polarizability = $\alpha_e = 4\pi\varepsilon_0 R^3$ (Farad.m^2) where R is the radius of the atom.

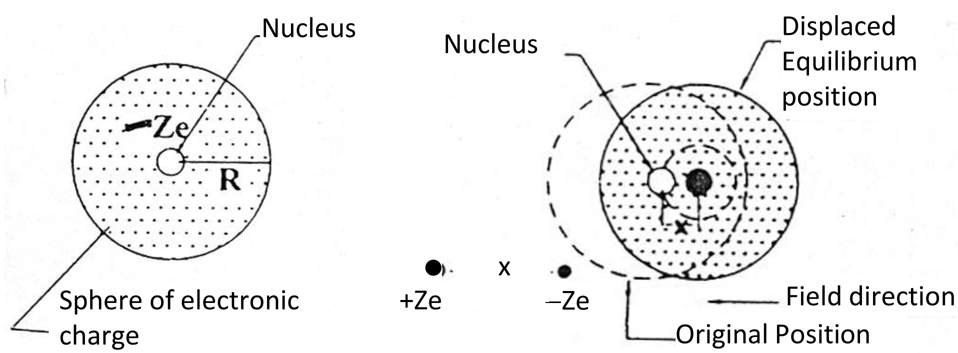

Fig. (a) Position of +ve and –ve charges in an atom without field (b) Position of +ve and –ve charges in an atom with field

ii. Ionic Polarization

Ionic polarization arises **due to the displacement of -ve ions and + ve ions in opposite directions** and it occurs in ionic solids, in the presence of electric field. The displacement is independent of temperature. **Example : NaCl crystal**

Ionic Polarizability = α_i = $$\frac{e^2}{\omega_0^2}\left(\frac{1}{m}+\frac{1}{M}\right)$$

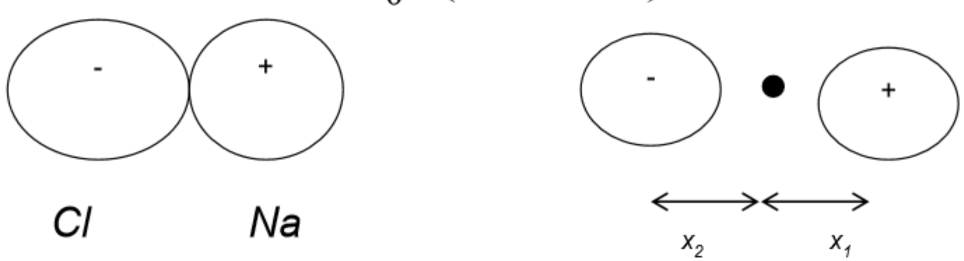

Fig. (a) Without field (b) With field

iii. Orientation Polarization

The orientation polarization arises due to the presence of polar molecule in the dielectric medium.

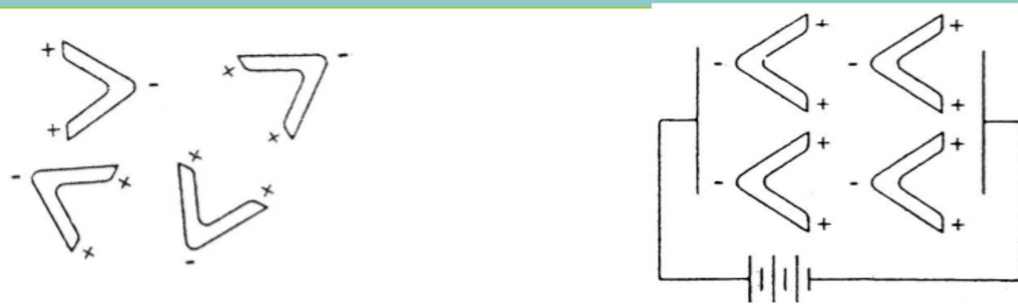

Fig. (a) Without field (b) With field

From Langevin's theory of Paramagnetism, net intensity of magnetization = $\dfrac{N\mu^2 B}{3K_B T}$

Orientation polarization (P_0) = $\dfrac{N\mu^2 E}{3K_B T}$ = $N\alpha_0 E$

➢ ***Explanation*:**

➢ In the case of a CH_3Cl molecule, the positive and negative charges do not coincide. The Cl^- has more electro negativity than hydrogen. Therefore, the chlorine atoms pull the bonded electrons towards them more strongly than hydrogen atoms. Therefore, even in the absence of field, there exists a net dipole moment.

➢ Now, when the field is applied, positive portion align along the direction of field and negative portion align in the opposite direction of the field. This kind of polarization is called as orientation polarization.

➢ This depends on temperature; when temperature is increased, the thermal energy tends to randomize the alignment

Explanation

- Without the application of external field, the ions are orderly arranged as shown in the Fig.
- Now, when the field is applied, the ions diffuse with respect to the direction of applied field. Thus the polarization occurs, known as space charge polarization.
- Normally, this type of polarization occurs in ferrites and semiconductors and will be very small.

Space-Charge Polarization

The space-charge polarization occurs due to the diffusion of ions, along the field direction, thereby giving rise to redistribution of charges in the dielectrics

Fig. (a) Without field (b) With field

➢ *Explanation*

- ➢ Without the application of external field, the ions are orderly arranged as shown in the Fig.
- ➢ Now, when the field is applied, the ions diffuse with respect to the direction of applied field. Thus the polarization occurs, known as space charge polarization.
- ➢ Normally, this type of polarization occurs in ferrites and semiconductors and will be very small.

$$\alpha = \alpha_e + \alpha_i + \alpha_0 = 4\pi\varepsilon_0 R^3 + \frac{e^2}{\omega^2{}_0}\left(\frac{1}{m}+\frac{1}{M}\right) + \frac{\mu^2}{3K_B T}$$

We know that, total polarization $\boldsymbol{P = N\mu =}$ $NE\alpha$ **Note: $\mu = \alpha E$**

$$\therefore P = NE\alpha = NE \left[4\pi\varepsilon_0 R^3 + \frac{e^2}{\omega_0^2}\left(\frac{1}{m}+\frac{1}{M}\right) + \frac{\mu^2}{3K_B T}\right]$$

This equation is called as Langevin – Debye equation

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Frequency and Temperature Dependence of Polarization Mechanisms

(a) Frequency dependence

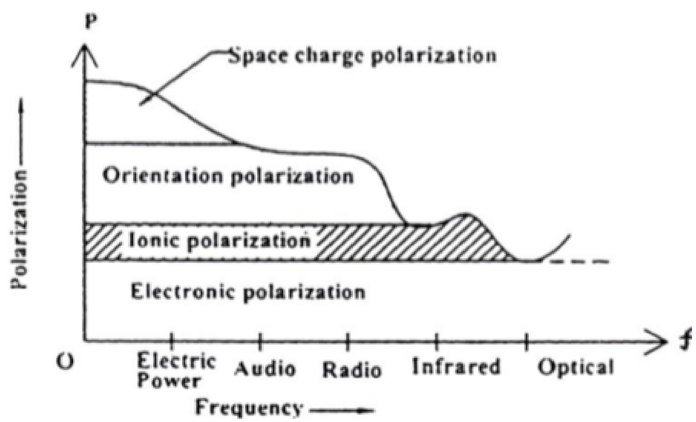
Electronic Polarization is very rapid and will complete at the instant the voltage is applied; the reason is that the electrons are very light elementary particles than ions. Therefore, even for very high frequency applied voltage i.e. in the optical range ($=10^{15}$Hz) as shown in Fig.2.22. This kind of polarization occurs during every cycle of the applied voltage.

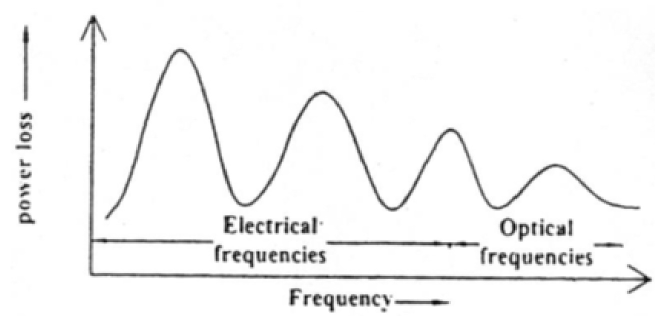
Ionic polarization is slightly slower than the electronic polarization. Because ions are heavier than the electron cloud. In addition, the frequency of the applied electric field with which the ions will be displaced is equal to the frequency of the lattice vibrations (-10^{13} Hz). At optical frequencies, there is no ionic polarization. If the frequency of the applied voltage is less than 10^{13} Hz, i.e. infrared range as shown in Fig.2.22, the ions have enough time to respond during each cycle of the applied field.

Orientation Polarization ***is even slower*** than ionic polarization.

The relaxation time for this case varies with respect to the dielectric materials (i.e. solids or liquids) used. Here the polar molecules in a liquid easily reorient themselves compared to solids. This type of polarization occurs at audio and radio frequency ranges ($=10^6$Hz) as shown in Fig.2.22.

Space charge polarization is the slowest process, because in this case the ions have to diffuse (jump) over several interatomic distances. Also this process occurs at very low frequency in the order 10^2 Hz as shown in Fig.2.22.





(b) Temperature Dependence

The electronic and ionic polarizations are independent of temperature, whereas the orientation and space charge polarizations are temperature dependent.

The orientation polarization decreases with the increase in temperature because the randomizing action of thermal energy decreases the tendency of the permanent dipoles to align along the field direction. Hence, in this case the ε_r decreases. However, in space charge polarization, when the temperature is increased, the ions can easily overcome the activation barrier and hence they diffuse through the inter atomic distances. Thus, it gives rise to polarization. So in this case the ε_r will increase with the increase in temperature.