

# Free Study Material from All Lab Experiments



**Solid-State Physics Notes  
for NET/GATE Physical Sciences  
# Ferroelectric Materials #**

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Dielectrics :- Dielectrics are perfect insulators. They are of two types.

- i) polar dielectrics
- ii) Non polar "

polar dielectrics are those dielectrics whose molecules (are contains characteristic by) the permanent dipole moment. ex -  $H_2O$ ,  $NaCl$ ,  $KCl$

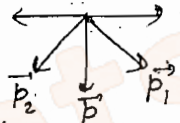
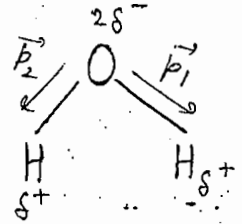
Non polar - those does'nt contains permanent dipole moment.

Ex - Solid -  $Ar$



$H_2O$  :-

Electronegativity of  $O$  is higher than  $H$  so it will acquire more -ve charge. so it contains permanent dipole mom. it is the inherent property of molecule.



if we apply external  $E$ -field on non-polar dielectric then it will be polarised & this polarisation is called induced polarisation or induced dipole moment.

$$\vec{p}_{in} \propto \vec{E}$$

$$\boxed{\vec{p}_{in} = \alpha \vec{E}_{loc}} \quad \text{--- (1)}$$

$\alpha \Rightarrow$  polarisability of atom or molecule

$\vec{E}_{loc} \Rightarrow$  local electric field

Polarisation :- dipole mom. per unit volume

$$\boxed{\vec{P} = \epsilon_0 \chi_e \vec{E}_{mac}} \quad \text{--- (2)}$$

$E \Rightarrow$  Macroscopic electric field

for Non-polar dielectrics;

If we have a large parallel plate capacitor & we filled a non-polar dielectric b/w its plates. Suppose external applied field is  $E$ . Due to this  $E$ , non-polar dielectric will be

polarised then plates acquire some bound charge.  
 & Electric field develop is,  $E$ , which is less than  $E_0$ .

Resultant  $E$  field,

$$\vec{E} = \underbrace{\vec{E}_0 + \vec{E}_1}_{E_{mac}}$$

Macroscopic  $E$  field is average  $E$  field seen b/w the plates.

If there is a molecule b/w plates then it will behave as dipole & resultant field on this molecule is different from  $E_{mac}$  & this  $E$  field is called local field.

$$\vec{E}_{loc} = \vec{E}_0 + \vec{E}_1 + \vec{E}_2 + \vec{E}_3$$

Take a spherical cavity out, from the surrounding of molecules. This is called spherical cavity Lorentz cavity.



$\vec{E}_0 \rightarrow$  Externally applied  $E$  field

$\vec{E}_1 \rightarrow$  depolarisation field

$\vec{E}_0 + \vec{E}_1 \rightarrow$  Macroscopic field

$\vec{E}_2 \rightarrow$  field due to the induce charges on the surface of the cavity (polarisation field)

$\vec{E}_3 \rightarrow$  field due to all the charges inside the cavity

Resultant of all these fields is the local field.

If the dipole is at the centre of the cavity then charges on the cavity will be symmetric about centre.

So  $\boxed{\vec{E}_3 = 0}$  (due to symmetry)

Now, 
$$\vec{E}_{loc} = \vec{E}_0 + \vec{E}_1 + \vec{E}_2$$

$$\vec{E}_{loc} = E_{mac} + \vec{E}_2$$

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

$$\left( E_2 = \frac{\vec{P}}{3\epsilon_0} \right)$$

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If solid contains  $N$  atoms (or molecules) per unit volume, each atom due to the application of  $\epsilon$ -field will become dipole so there will be  $N$  dipoles.

$$\vec{P} = N \vec{p}_{in}$$

$$\vec{P} = N \alpha \vec{E}_{loc} \quad (2)$$

from (2) & (3),



$$N \alpha \vec{E}_{loc} = \epsilon_0 \chi_e \vec{E}_{mac} \quad (\chi_e = \epsilon_r - 1)$$

$$N \alpha \vec{E}_{loc} = \epsilon_0 (\epsilon_r - 1) \vec{E}_{mac}$$

$$\frac{\vec{E}_{loc}}{\vec{E}_{mac}} = \frac{\epsilon_0 (\epsilon_r - 1)}{N \alpha}$$

$$\Rightarrow \frac{(\epsilon_r - 1)}{(\epsilon_r + 2)} = \frac{N \alpha}{3 \epsilon_0} \Rightarrow \text{Clausius-Mossotti Relation}$$

This is valid only for non-polar molecules.

$$\alpha = \alpha_e + \alpha_i$$

$\alpha_e \rightarrow$  electronic polarisability

$\alpha_i \rightarrow$  ionic "

Physical Significance of Clausius-Mossotti relation  $\rightarrow$  This

establish a relation b/w  $\alpha$  &  $\epsilon_r$ .

$\alpha \rightarrow$  Microscopic quantity

$\epsilon_r \rightarrow$  Macroscopic " (dielectric constant)

$\alpha$  corresponds to dipole mom so it is microscopic

$\epsilon_r$  " " polarisation " " macroscopic

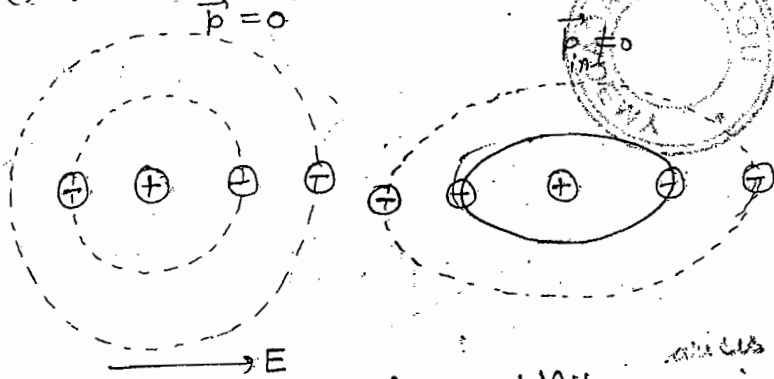
for Polar molecules, this Eq<sup>n</sup> becomes Lorentz-Lorentz - Debye Eq<sup>n</sup>.

For Rabi

## Types of polarisability :-

$$\alpha = \underbrace{\alpha_e + \alpha_i}_{\text{induced}} + \underbrace{\alpha_d}_{\text{Permanent}}$$

### (i) Electronic Polarisability ( $\alpha_e$ )



Unit of  $\alpha$

C.G.S.  $\Rightarrow$  volume  $\rightarrow \text{cm}^3$

M.K.S.  $\Rightarrow \text{F} \cdot \text{m}^2$



This type of polarisability arises due to displacement of  $e^-$  cloud of an atom relative to its nucleus in the presence of applied electric field.

$$\alpha_e = 4\pi \epsilon_0 R^3$$

$R \rightarrow$  radius of the atom

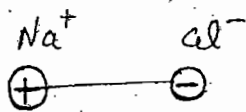
This type of polarisability is independent of temp. but depend on the freq. of applied electric field.

$$\alpha_e = \frac{e^2}{m(\omega_0^2 - \omega^2)}$$

This is the freq. dependence of  $\alpha_e$ .

- $m \rightarrow$  mass of the  $e^-$ . &  $e \rightarrow e^-$  charge.
- $\omega_0 \rightarrow$  Natural freq. of oscillation of atom.
- $\omega \rightarrow$  freq. of applied electric field.

### (ii) Ionic Polarisability ( $\alpha_i$ )



$\rightarrow E$

This type of polarisability arises due to increase of or decrease in the bond length of a ions.

This type of polarisability is independent of temp. but depends on the freq. of applied field.

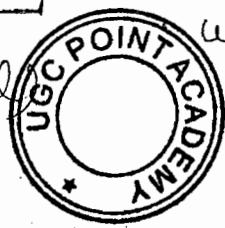
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$$\alpha_i = \frac{e^2}{\omega_0^2} \cdot \left( \frac{1}{m} + \frac{1}{M} \right)$$

$m \rightarrow$  mass of 1 ion ( $\text{Na}^+$ )  
 $M \rightarrow$  " " another ion (Cl<sup>-</sup>)

$\omega_0 \rightarrow$  natural freq. of the vibration of molecule (NaCl)

$$\alpha_i \approx \frac{\alpha_e}{10} \quad (\text{in general})$$



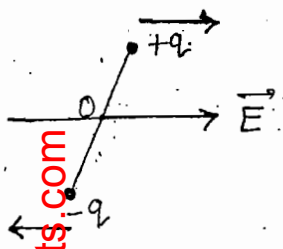
(iii) Dipolar Polarizability :- ( $\alpha_d$ )

This type of polarizability arises due to the permanent dipole mom. of the molecule.

$$\alpha_d = \frac{p_p^2}{3k_B T}$$

$p_p \rightarrow$  permanent dipole mom. of the molecule.

$\alpha_d$  depends on both temp. & freq. of the field.



Hence total polarizability,

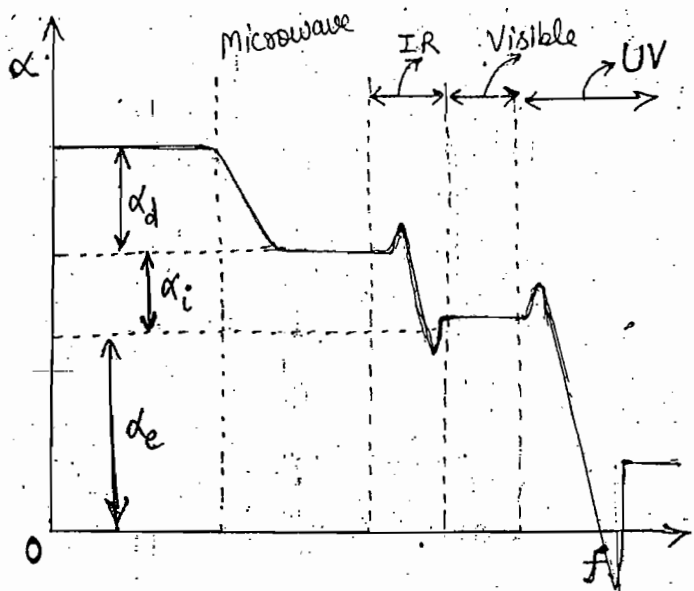
$$\alpha = \alpha_e + \alpha_i + \alpha_d$$

$$\alpha = \alpha_0 + \frac{p_p^2}{3k_B T}$$

$\Rightarrow$  Langevin - Debye Equation.

This is valid for polar molecules.

Frequency Dependence of Total Polarizability :-



In visible region, Total polarisation is electronic polarisation ( $\alpha_e$ )  $\alpha = \alpha_e$

$\rightarrow$  Existence of  $\alpha_i, \alpha_d, \alpha_e$  depends upon the Relaxation time ( $\tau$ )

$\rightarrow$  lesser the  $\tau$ , faster the response.

$$f \propto \frac{1}{\tau}$$

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$$\tau_e < \tau_i < \tau_d$$

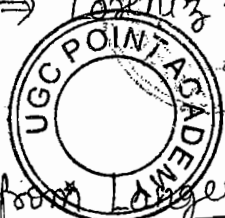
At optical freq. or visible freq. :-

$$\alpha = \alpha_e$$

We have  $\epsilon_r = n^2$

$$\frac{n^2 - 1}{n^2 + 2} = \frac{N \alpha_e}{3 \epsilon_0}$$

Lorentz - Lorentz Relation



Static Dielectric Constant from Langevin - Debye Equation -

Total polarisability  $\alpha = \alpha_e + \alpha_i + \alpha_d$   
 $= \alpha_e + \alpha_i + \frac{p_p^2}{3 K_B T}$

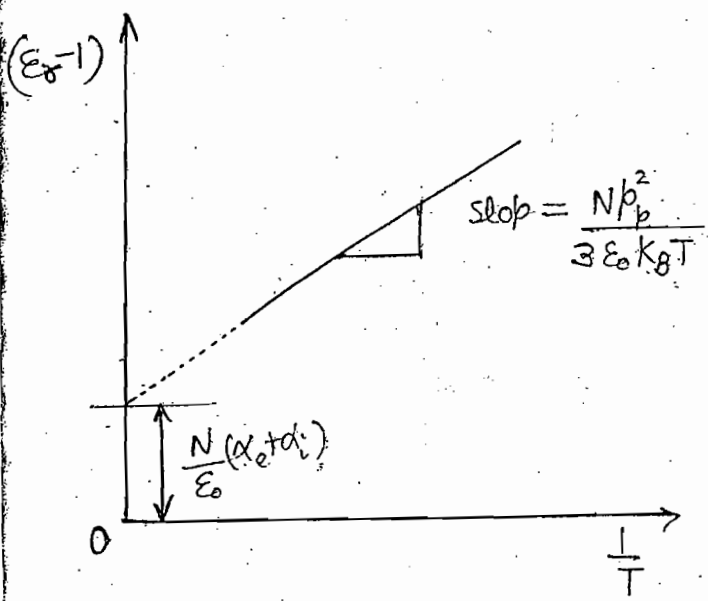
$$\Rightarrow \vec{p} = \epsilon_0 (\epsilon_r - 1) E_m = N \alpha E_{loc}$$

if  $E_{loc} = E_m$

This is possible if seperation b/w atoms & molecules is so large that there is no interaction b/w the dipoles like in liquid or gasses.

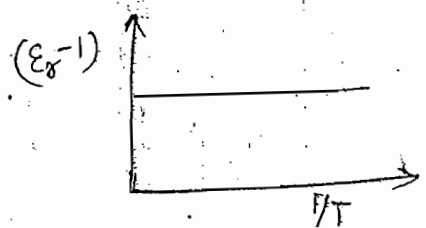
So  $\vec{p} = \epsilon_0 (\epsilon_r - 1) E_m = N \alpha E_{loc}$

$$(\epsilon_r - 1) = \frac{N}{\epsilon_0} (\alpha_e + \alpha_i) + \frac{N p_p^2}{3 \epsilon_0 K_B T}$$

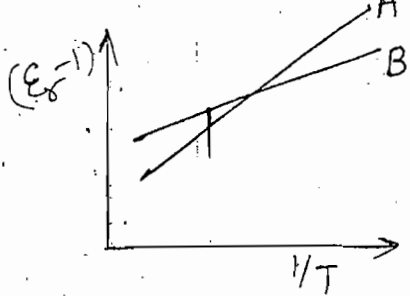


More slope  $\Rightarrow$  More polar  
 More intercept  $\Rightarrow$  More  
 electronic & ionic  
 polarisabilities

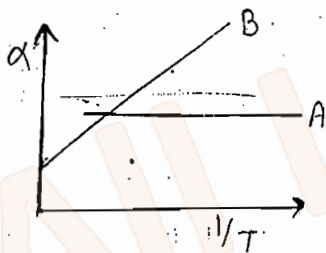
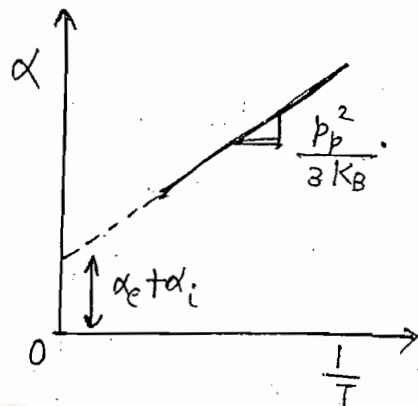
If graph is flat  $\rightarrow$   
 means molecule is Non-polar



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A is more polar  
beoz, more slop → more polar.



These have permanent dipole mom. → B

- (i) CH<sub>4</sub> → A  
 (ii) CO<sub>2</sub> → A  
 (iii) H<sub>2</sub>O → B  
 (iv) HCl → B  
 (v) CO → B  
 (vi) CS<sub>2</sub> → A  
 (vii) SO<sub>2</sub> → B  
 (viii) NO<sub>2</sub> → B

### Questions

Q.1 (A) Calculate the static dielectric constant  $\epsilon_r$  of solid Argon using Clausius-Mossotti Eqn 4 following data

$$\alpha_e = 1.7 \times 10^{-40} \text{ F-m}^2$$

$$M_A = 39.95$$

$$\rho_m = 1.8 \text{ gm/cm}^3$$

(B) Will the result of part (A) be effected if  $\epsilon_r$  is calculated

$$\text{from } P = \epsilon_0 (\epsilon_r - 1) E \\ = N \alpha_e E$$

Give reasons for your answer.



Q.2:- A material has refractive index of 2. What is the dielectric constant at the frequencies corresponding to the visible part of the electromagnetic spectrum.

Q.3:- Refractive index of an elemental semiconductor in the visible range is 1.5. Find the polarisability of the material if atomic density is  $2.1 \times 10^{22}/\text{cm}^3$ .

Q.4:- Determine the % of ionic polarisability in NaCl crystal which has optical index of refraction as 1.5 & dielectric constant as 1.6.

