UNIT – III

UNIT-III DIELECTRIC PROPERTIES

1) Dielectrics is an insulating material with high specific Resistance.

The temperature coefficient of Resistance is negative.

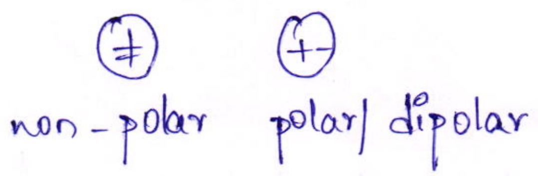
Dipole:- Slight/small displacement of +ve and -ve charge is called dipole.

Dipolement:- (μ) Magnitude of charge into the distance between the two charges.

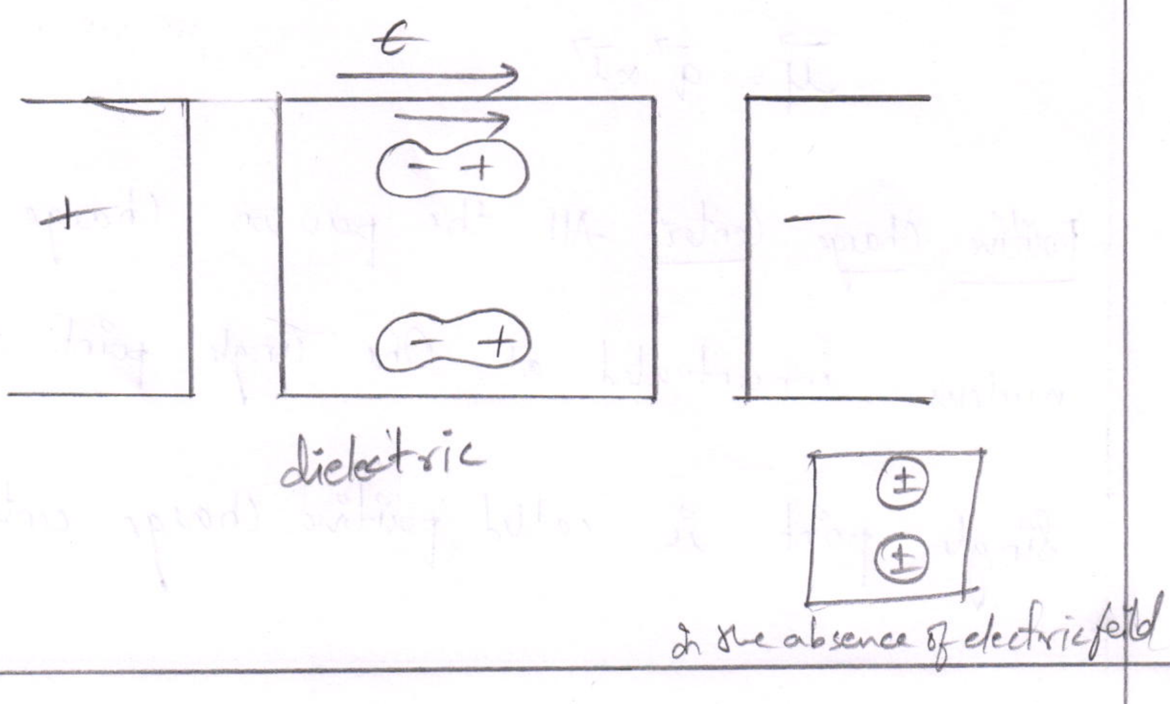
$$\vec{\mu} = \vec{q} \times \vec{l}$$

Positive Charge Center:- All the proton charge of nucleus concentrated at one single point that single point is called positive charge center.

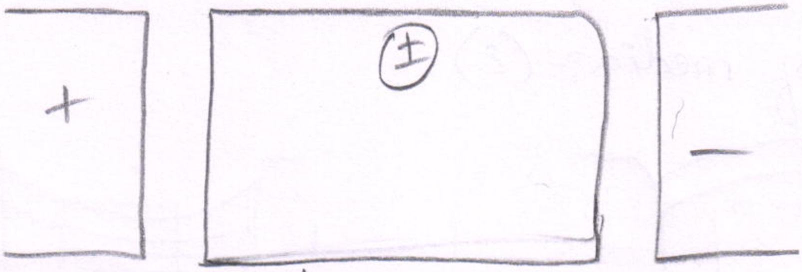
Negative Charge center :- The entire charge of the electrons in the atom concentrated at one single point which is called negative charge center.



Polarisation :- the process of producing the dipoles which are Oriented along with field direction is called polarisation.



Polarizability :- (α) dipolement for Unit electric field is called 'α'



at $\epsilon = 0$

dipolemoment for unit Electric field is called α

the $\vec{\mu} = q \times \vec{l}$

at $\epsilon = 0 \Rightarrow \vec{\mu} = 0$ if $l = 180°$

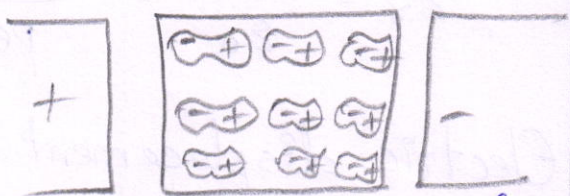
$\epsilon = 10 \Rightarrow \vec{\mu} = q(l)$

$\therefore \vec{\mu} \propto \vec{E}$

$\vec{\mu} = \alpha \vec{E}$

$\alpha = \frac{\vec{\mu}}{\vec{E}}$ at $\epsilon = 1 \Rightarrow \alpha = \vec{\mu}$

Polarization vector ($\vec{P}$) :-



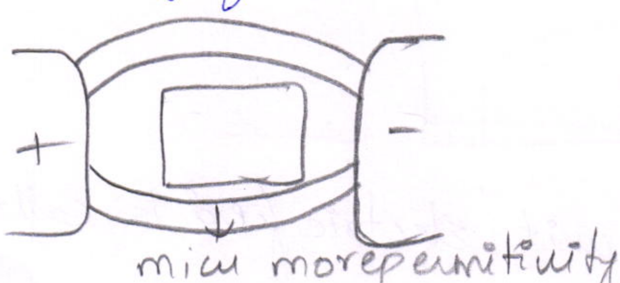
$\vec{P}$ = the magnitude of dipolement for unit volume is called polaraisation vector $\vec{P}$ If it is the average magnitude of dipolement

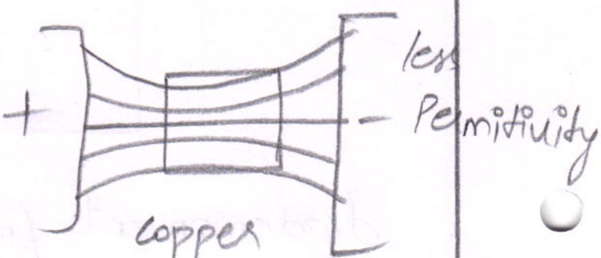
If 'N' is the no. of atoms / moleeules per unit volume $\vec{P} = N\vec{\mu}$

Electric lines of force :-

the path of unit +ve charge in the electric field is called Electric line of force

Permitivity of media :- (ε)





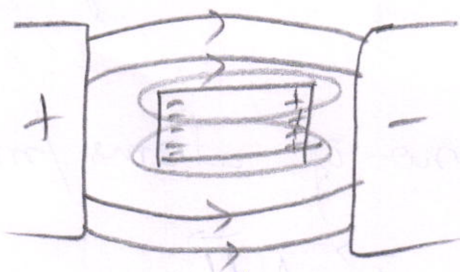
the materials ability to resist the Electric lines of force (or) Electric field is called permiti-vity of that material.

Relative permitivity of materials (or) dielectric constant

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0} = \frac{\text{Permitivity of material (media)}}{\text{permitivity of free space}}$$

Electric displacement vector P:-

the Electric flux density is called Electric displacement



the displacement vector in the media is

D = Electric lines of force due to External Electric field + E.L of force due to polari-sed charge

$$\therefore \quad D = \varepsilon_0 E + P$$

$$\varepsilon_r \cdot \varepsilon_0 E = \varepsilon_0 E + P$$

$$P = \varepsilon_0 E [\varepsilon_r - 1]$$

$$D = \varepsilon E \rightarrow ②$$

$$\vec{P} \propto E$$

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

$$\vec{P} = \varepsilon_0 \chi_e E$$

$$\Rightarrow \varepsilon = \varepsilon_r \varepsilon_0$$

$$D = \varepsilon_0 \varepsilon_r E$$

How easily we can polarise the material we need a physical quantity (suceptability)

* If suceptability is high we can easily polarise the material
* If it is low then we cannot polarise the ma-terial easily.

The relation b/w (ε_r & χ_e):-

we know $D = \varepsilon_0 E + P$ But $P = \varepsilon_0 \chi_e E$

$$\varepsilon_0 \varepsilon_r E = \varepsilon_0 E + P$$

$$\varepsilon_0 \varepsilon_r \cdot E = \varepsilon_0 E + \varepsilon_0 \chi_e \cdot E$$

$\varepsilon_r = 1 + \chi_e$

Various polarisation techniques.

1. Electronic polarisation
2. Ionic polarisation
3. orientation polarisation
4. space charge polarisation.

charge density 'e' of atom $= \frac{\text{charge}}{\text{Volume}} = \frac{-Ze}{\frac{4}{3}\pi r^3}$

$$e = \frac{-3}{4} \cdot \frac{Ze}{\pi R^3}$$

due to External electric field the force on Electron cloud is

lorentz force $F_r = E(-Ze)$ – ②

the coloumb force b/w two charge centre is

$$F_C = \frac{1}{4\pi} \frac{q_1 q_2}{r^2}$$

$$\Rightarrow F_c = \frac{1}{4\pi\varepsilon_0} \frac{(Ze)(\text{charge of the sphere of radius } r)}{x^2} \quad ③$$

∴ The charge on the sphere of radius 'x'

= charge density × volume of sphere of radius 'x'

$$= \frac{-3}{4} \times \frac{Ze}{\pi R^3} \times \frac{4}{3}\pi x^3$$

charge on the sphere of radius $x = -\frac{Ze}{R^3} x^3$ — (4)

sub Eq^n (4) in (3)

$\therefore F_C = \frac{1}{4\pi\varepsilon_0}(Ze) \cdot \frac{(-Ze)}{R^3} \times \frac{x^3}{x^2}$

$$F_C = \frac{-Z^2e^2x}{4\pi\varepsilon_0 R^3} \quad \text{— (5)}$$

at Equilibrium position $F_L = F_C$

$$(-Ze)E = -\frac{Z^2e^2 x}{4\pi\varepsilon_0 R^3}$$

$$\therefore x = \frac{4\pi\varepsilon_0 R^3 \cdot E}{Ze} \quad \text{— (6)}$$

dipole moment $\vec{\mu} = (Ze) \cdot x$

$$= \frac{\cancel{(Ze)} \cdot 4\pi\varepsilon_0 R^3 \cdot E}{\cancel{Ze}}$$

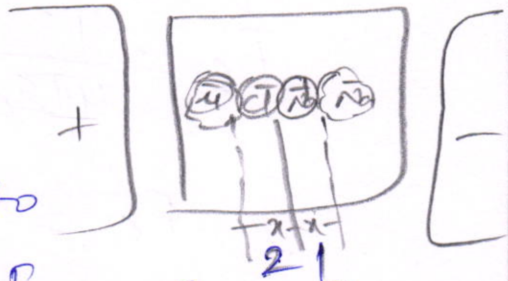
$$\vec{\mu} = 4\pi\varepsilon_0 R^3 \cdot E$$

$\therefore$ Electronic polarisatrility $\alpha_E = \frac{\vec{\mu}}{E}$

$$\Rightarrow \alpha_E = 4\pi\varepsilon_0 R^3$$

IONIC POLARISATION:- The ionic polarisation is due to the displacement of cations & anions in opposite directions & occur in ionic solids suppose an electric field is applied in +ve x-axis direction. The +ve ion moves to the right side by x_1 . -ve ion move towards left by x_2.

In presence of External Electric field the displacement of cation is x_1, due to lorentz force on cation is $F_L = \epsilon e$ — ①



The restoring force of cation is $F_r = B_1 x_1$ — ②

$$F_r = m\omega_0^2 \cdot x_1 \rightarrow ③$$

Here $\beta_1 = m\omega_0^2$ $B_1 \rightarrow$ restoring force const of cation

$m \rightarrow$ mass of cation

$\omega_0 \rightarrow$ angular frequency of molecule

$x_1 \rightarrow$ displacement of cation

at Equilibrium state

$$F_L = F_R \Rightarrow e\epsilon = m\omega_0^2 \cdot x_1$$

$$x_1 = \frac{e\epsilon}{m\omega_0^2} \rightarrow ④$$

Illy due to External Electric field

The Lorentz force on the Anion is $F_L = e\epsilon$ — ⑤

The restoring force of Anion is $F_r = B_2 \cdot x_2$ — ⑥

but $\beta_2 = M\omega_0^2$

$$⑥ \Rightarrow F_r = M\omega_0^2 \cdot x_2 \; ⑦$$

Here $M \rightarrow$ mass of anion - $\omega_0 \rightarrow$ angular freq. of molecule

$x_2 \rightarrow$ displacement of Anion

$\therefore$ at Equilibrium position $F_L = F_r$

$$eE = M\omega_0^2 \cdot x_2 \Rightarrow x_2 = \frac{eE}{M\omega_0^2} \quad \text{—(8)}$$

$\therefore$ Total distance b/w two ions is $x_1 + x_2$

$$= \frac{eE}{m\omega_0^2} + \frac{eE}{M\omega_0^2} \quad \text{—(9)}$$

$\therefore$ dipolement $\vec{\mu} = e(x_1 + x_2)$

$$\vec{\mu} = e\left(\frac{eE}{m\omega_0^2} + \frac{eE}{M\omega_0^2}\right)$$

The ionic polarisability

$$\alpha_I = \frac{\mu}{E} = \frac{e^2}{\omega_0^2}\left[\frac{1}{M} + \frac{1}{m}\right]$$

$\therefore$ polarisation vector $\vec{P} = N\alpha_I E$

$$\vec{P} = \frac{NEe^2}{\omega_0^2}\left[\frac{1}{m} + \frac{1}{M}\right]$$

ORIENTATION POLARISATION:-

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

the orientation polarisation greately depends on temp

the orientation polarisability: $\alpha_0 = \frac{\mu^2}{3KT}$

μ = dipolemoment of molecule

K = Boltzmann constant

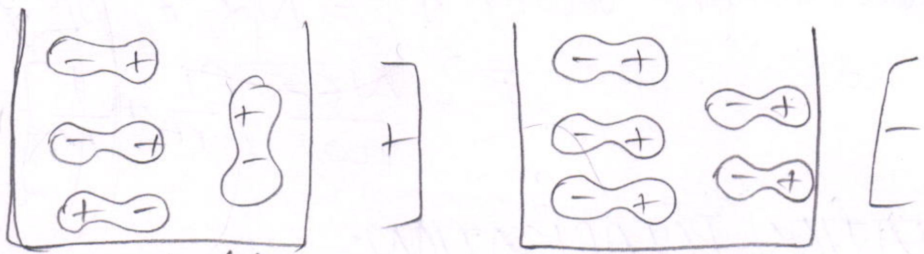
T = temp of material

polarisation vector $P_0 = N\alpha_0 E$

$$P_0 = NE \cdot \frac{\mu^2}{3KT}$$

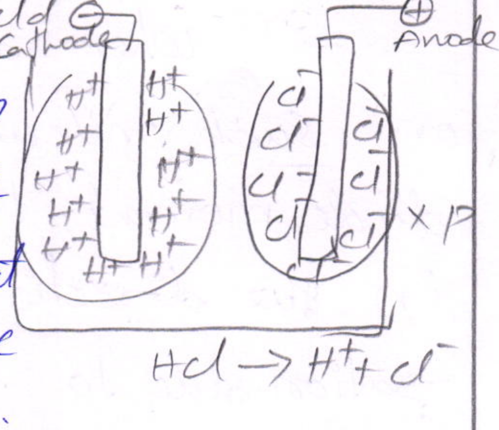
$$P_0 = \frac{NE\mu^2}{3KT_0}$$

Space charge polarisation:- (Generally occurs in liquid)



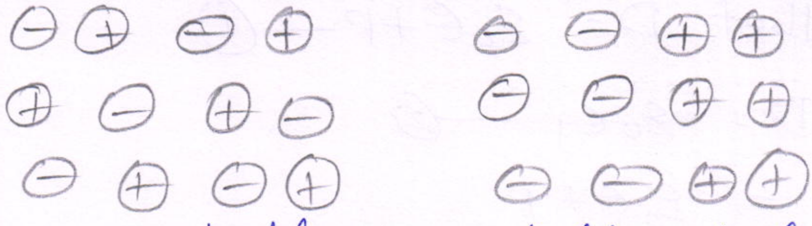
No field

field



$HCl \rightarrow H^+ + Cl^-$

Space charge polarisation occurs due to accumilation of charges at the Eletrodes (or) at the interface in a multiphase material as shown in fig.



No field　　　　field applied

the total polarizability in any material is

$$\alpha_T = \alpha_e + \alpha_I + \alpha_0 + \alpha_s$$

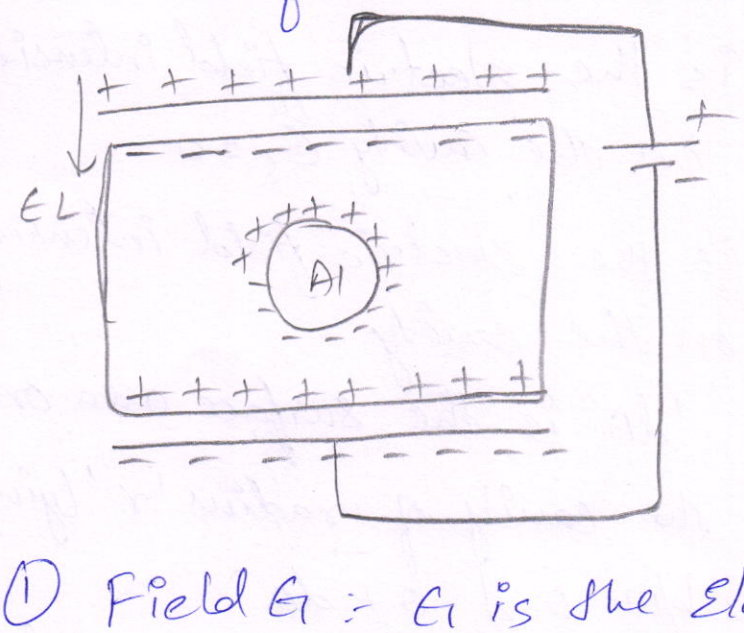
$$\alpha_T = 4\pi\varepsilon_0 R^3 + \frac{e^2}{\omega_0^2}\left[\frac{1}{M} + \frac{1}{m}\right] + \frac{\mu^2}{3k_T} + 0$$

The polarisation vector $P = N\alpha E$

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

This Eq^n is called Langevin Debye Equation

* Internal fields in solids (Lorentz method) :-



① Field E_1 :- E_1 is the Electric field intensi-ty at 'o' due to charges on the capacitor plates we know that $D = \varepsilon_0 E + P$ — ①

at 'n' $D = \varepsilon_0 E_1$ — ②

$\varepsilon_0 E_1 = \varepsilon_0 E + P$

$E_1 = E + \frac{P}{\varepsilon_0}$ — ③

② Field E_2 :- E_2 is the Electric field intensity at 'A' due to polarised charges $E_2 = \frac{-P}{\varepsilon_0}$

$\therefore E_2 = \frac{-1}{4\pi\varepsilon_0} \cdot \frac{q_1}{r^2}$

$= \frac{-q}{4\pi r^2} \cdot \frac{1}{\varepsilon_0}$

$= \frac{-q}{A} \cdot \frac{1}{\varepsilon_0}$

$E_2 = -P/\varepsilon_0$

$P = \frac{\mu}{V}$

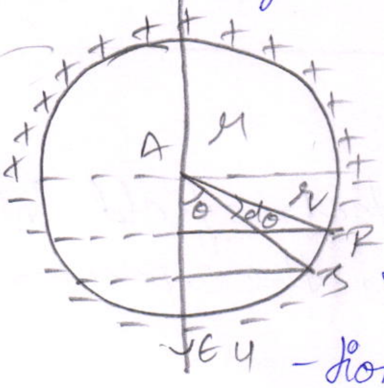
$= \frac{q \times l}{V}$

$P = \frac{q \times l}{A \times l}$

$P = q/A$

③ Field E_3 :- E_3 is the electric field intensity due to molecules in the cavity $E_3 = 0$

④ Field E_4 :- E_4 is the electric field intensity due to charge on the cavity



'dA' is the surface area on the cavity of radius 'r' lying b/w θ & $\theta + d\theta$

'θ' is the angle b/w E_4 direction & AP

The surface area of loop on the cavity dA

$$= 2\pi (PQ)(QR) \underset{l \times B}{} \text{ --- (6)}$$

In ΔAPQ $\sin\theta = \frac{PQ}{AQ} \Rightarrow PQ = r\sin\theta$ --- (7)

In ΔQAR $\sin d\theta = \frac{QR}{AR} \Rightarrow QR = AR\sin d\theta$

$QR = r d\theta$ --- (8)

Sub Eq^n (7) & (8) in (6)

$$dA = 2\pi \times r\sin\theta \cdot r d\theta ..$$

$$dA = 2\pi r^2 \cdot \sin\theta \, d\theta \text{ --- (9)}$$

If dq is the charge on the 'dA' area

$$dq = P\cos\theta \cdot dA \text{ --- (10)}$$

only normal component of polarization vector Can give the charge

$$dq = P\cos\theta \cdot 2\pi r^2 \cdot \sin\theta d\theta \text{ --- (11)}$$

dE_4 is the electric field intensity at A due to dq charge

$$dE_4 = \frac{dq \cdot \cos\theta}{4\pi\varepsilon_0 \cdot r^2}$$

$F = EQ$

$E = \frac{1}{4\pi\varepsilon_0} \times \frac{q}{r^2}$

$$dE_4 = \frac{P\cos\theta \cdot \cancel{2\pi} \cancel{r^2} \sin\theta \cdot d\theta \cdot \cos\theta}{2 \cancel{\pi} \varepsilon_0 \cdot \cancel{r^2}}$$

$$dE_4 = \frac{P\cos^2 \sin\theta d\theta}{2\varepsilon_0}$$

The electric field intensity at 'A' due to entire chargeon cativity

$$E_4 = \int_0^{\pi} dE_4 = \int_0^{\pi} \frac{P}{2\varepsilon_0} \cos^2\theta \cdot \sin\theta \cdot d\theta$$

put $\cos\theta = x$ say.

$$-\sin\theta \cdot d\theta = dx$$

$$\Rightarrow \int_1^{-1} \frac{-P}{2\varepsilon_0} \cdot x^2 dx \Rightarrow \frac{+P}{2\varepsilon_0} \int_{-1}^{1} x^2 dx$$

$$\Rightarrow \frac{\cancel{2}P}{\cancel{2}\varepsilon_0} \int_0^1 x^2 \cdot dx.$$

$$\Rightarrow \frac{P}{\varepsilon_0} \left(\frac{x^3}{3} \right)_0^1 \Rightarrow \frac{P}{3\varepsilon_0} = E_4 \text{ --- } (13)$$

$\therefore$ The total electric field intensity at 'n'

$$E = E_1 + E_2 + E_3 + E_4$$

$$= E + \cancel{\frac{P}{\varepsilon_0}} - \cancel{\frac{P}{\varepsilon_0}} + 0 + \frac{P}{3\varepsilon_0}$$

$$E = E + \frac{P}{3\varepsilon_0}$$

Internal
field

Internal field (or) Lorentz internal field Eq^n

CLASIUS — MOSOTTI EQUATION

Let us consider the External dielectric material In that dieletrics & no permanent dipoles & ions Due to that ionic polarisa-bility & orientation polaraisability is zero
The total polarisation $\alpha_T = \alpha_e + \alpha_I + \alpha_0$

$$\alpha_T = \alpha_e$$

the polaraisation vector $\vec{P} = N\alpha E$

$$\vec{P} = N\alpha_e E_i \quad E_i = \text{internal electric field}$$

α_e = Electronic polar-izability

N - No. of atoms (or) molecules/ unit volume

$$P = N\alpha_e \left[E + \frac{P}{3\varepsilon_0}\right]$$

$$\Rightarrow P = N\alpha_e E + \frac{N\alpha_e P}{3\varepsilon_0}$$

$$\Rightarrow P\left[1 - \frac{N\alpha_e}{3\varepsilon_0}\right] = N\alpha_e E$$

$$\Rightarrow P = \left[\frac{N\alpha_e E}{1 - \frac{N\alpha_e}{3\varepsilon_0}}\right] \longrightarrow (7)$$

we know that $D = \varepsilon_0 E + P$

but $D = \varepsilon E \Rightarrow D = \varepsilon_0 \varepsilon_r E$

$$\varepsilon_0 \varepsilon_r E = \varepsilon_0 E + P$$

$$P = \varepsilon_0 \varepsilon_r E - \varepsilon_0 E$$

$$dE_q = \frac{P\cos^2\theta \sin\theta d\theta}{2\varepsilon_0}$$

The Electric field intensity at 'A' due to entire charge on cavity

$$E_u = \int_0^{\pi} dE_u = \int_0^{\pi} \frac{P}{2\varepsilon_0} \cos^2\theta, \sin\theta d\theta$$

put $\cos\theta = x$ say

$$-\sin\theta . d\theta = dx.$$

$$\Rightarrow \int_1^{-1} \frac{-P}{2\varepsilon_0} x^2 dx \Rightarrow + \frac{P}{2\varepsilon_0} \int_{-1}^{1} x^2 dx$$

$$\Rightarrow \frac{\cancel{2}}{\cancel{2}} \frac{P}{\varepsilon_0} \int_0^1 x^2 dx$$

$$P = \varepsilon_0 E (\varepsilon_r - 1) \quad — (2)$$

from (1) & (2)

$$\varepsilon_0 \cancel{E} (\varepsilon_r - 1) = \frac{N\alpha_e \cancel{E}}{\left[1 - \frac{N\alpha_e}{3\varepsilon_0}\right]}$$

$$\left[1 - \frac{N\alpha_e}{3\varepsilon_0}\right] = \frac{N\alpha_e E}{\varepsilon_0 (\varepsilon_r - 1)}$$

$$\Rightarrow 1 = \frac{N\alpha_e}{\varepsilon_0 (\varepsilon_r - 1)} + \frac{N\alpha_e}{3\varepsilon_0}$$

$$\Rightarrow \left(\frac{\varepsilon_r - 1}{\varepsilon_r + 2}\right) = \frac{N \alpha_e}{3\varepsilon_0}$$

Clausius - Mosotti Eq^n.

Problems:- 1. Find the electric suceptability of a dielectric gas having dielectric constant of 1.000041.

Sol:- $\varepsilon_r = 1 + \chi_e$

$1.000041 = 1 + \chi_e$.

$\chi_e = 1.000041 - 1$

$= 0.000041$

2. The radius of gas atom is 0.0622m calculate the polarizability of the gas & its relative permitivity. Given that the no. of atoms of the gas is 2.7×10^{25} atom/m^3

PYRO ELECTRIC EFFECT:-

Pyroelectric effect is the charge in spontaneous polarasation when the temp of the specimen is changed

The pyro electric coefficient (λ) is defined change in polaraisation for unit temperature change of the specimen $(\lambda) = \frac{dP}{dt}$

Pyroelectric materials & their applications

1. pyroelectric materials such as Barium Titanate ($BaTiO_3$), $LiNbO_3$ Etc are used to makes very good infrared electrons which can operate at room temperature

2. Materials such as PGS, $NaNO_2$ & P_2T Ceramics are used in the construction of Pyroelectric image tubes.

FERRO ELECTRICITY:-

The ferro electric property is the possibility of reversal/change of orientation of polarisation direction by an electric field this leads to hysteresis in the polarisation P.

Ferro electric materials & their applications

Ferro electric materials & their exhibit Piezo electricity & pyroelectricity

FERRO e 32 crystal symmetry

- 12 are centro symmetry (the does not show) any property
- 20 are non centro symmetry (Piezo electric Property)
  - 10 unique polariaxis (Pyro) electricity
    - ferro electricity
    - Non ferro
  - 10 polari zations

Making use of piezo electric property, Ferro Electric materials such as quartz, lithium Lie'binate, barium titanate, Lead zirconium titanatax are used to make pressure teans bucers ultrasonic transurers & microphones.

Ferroelectric semiconductors such as

$BaTiO_3 - SrTiO_3$
$BaTiO_3 - PbTiO_3$
$SrTiO_3 - PbTiO_3$ are used to make

Possistors. positors are used to measure of control the temp

Fig: Piezo, Pyrro, Ferro electric materials are active dielectric materials. A material can be Piezo etelric, Pyrro. (or) Ferro electric only if its crystal symmetry. of the 32 crys-tal symmetry clauses. 12 have centro symmetry remaining are assymmetric properties. All the Materials in this 20 classes are piezoelectric Materials if 10 of these - 20 classes have a unique polar axis - the resistance of unique polar axis in crystal allows the appearance of the spontaneous electrical pola-risation & Hence these materials are pyroelec-tric. Few of the pyroelectric have the Property of the Ferro electric

Thus all ferro electrics are pyro electric & piezo electric. Slly all pyro electrics are pirzo electric, but the conversion is not true.