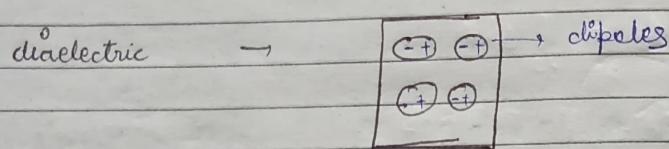
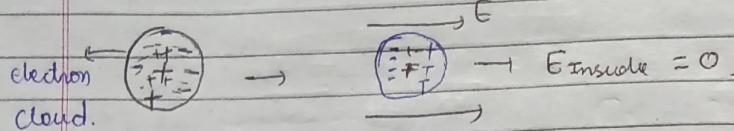


## ELECTRIC FIELD IN MATTER

Electric Polarisation.



as we know the dipole moment ( $\vec{P}$ )

$$\vec{P} = \text{charge} \times \text{separation}$$

$$\text{as } \vec{E} \uparrow \rightarrow \text{separation} \uparrow \rightarrow \vec{P} \uparrow$$

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

directly proportional

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

Proportionality constant called  
Polarisability

$\alpha \rightarrow$  Tensor quantity

If ' $n$ ' is the density of molecules

$n = \text{no. of molecules per unit volume.}$

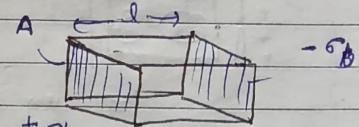
The no. of dipole moment [polarised molecule] in per unit volume is.

$$\vec{P}' = n \vec{p} = n \times \vec{p}$$

$\downarrow$   
Polarisation vector.

\* Relation between charge & polarisation vector.

$$\text{length} \rightarrow l, \text{area} \rightarrow A$$



charge / unit surface area

$b \rightarrow$  bound charge.

= charge  $\times$  length

$$(b \times A) \times l = b A l.$$

$$\text{Total D. m (unit volume)} = \frac{b A l}{A \times l} = b$$

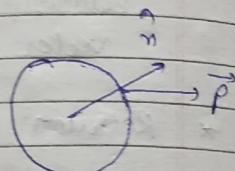
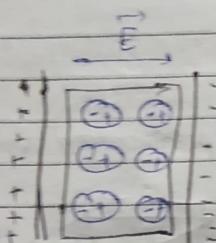
$$\boxed{\vec{P}' = b}$$

Three electric vectors ( $\vec{E}$ ,  $\vec{E}$ ,  $\vec{p}$ )

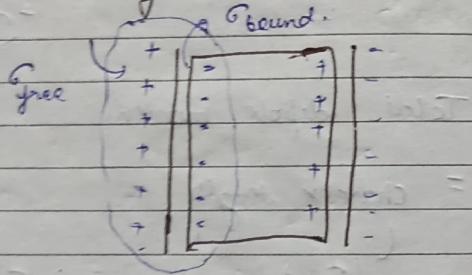
$\vec{p} \rightarrow$  polarisation vector



$$\sigma_p = \hat{n} \cdot \vec{p}$$



in case of dielectric:



$$\sigma_{\text{surface charge density}} = \sigma_{\text{free}} - \sigma_p$$

$$\epsilon = \epsilon_f - \epsilon_p$$

$$\vec{E} = \left( \frac{\epsilon}{\epsilon_0} \right) = \frac{\epsilon_f}{\epsilon_0} - \frac{\epsilon_p}{\epsilon_0}$$

$$\boxed{\vec{E} = \frac{\epsilon_f}{\epsilon_0} - \frac{\epsilon_p}{\epsilon_0}}$$

$$\vec{E} = \frac{\epsilon_{\text{free}} - \vec{p}}{\epsilon_0}$$

$$\epsilon_0 \vec{E} = \epsilon_{\text{free}} - \vec{p}$$

$$\boxed{\epsilon_0 \vec{E} + \vec{p} = \epsilon_{\text{free}}} = D$$

$$\epsilon_0 \vec{E} + \vec{p} = \vec{D}$$

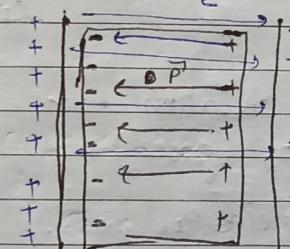
displacement vector

$$\boxed{\vec{D} = \epsilon_0 \vec{E} + \vec{p}}$$

$$\oint \vec{E} \cdot d\vec{s} = \frac{q}{\epsilon_0}$$

$$\oint \vec{D} \cdot d\vec{s} = q_{\text{free}}$$

Field lines  $\vec{E}$



$$n(k+2) \mid$$

## Magnetic Materials

1. Diamagnetic Materials
2. Paramagnetic Materials.
3. Ferromagnetic Materials.

### Diamagnetic Materials :-

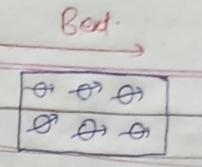
These materials gets weakly magnetised in presence of external magnetic field and direction of induced magnetisation is opposite to the applied magnetic field.

Ex:- Bismuth, Copper, Gold.

Paramagnetic Materials :- These material who gets weakly magnetised in the presence of external magnetic field & the induced magnetisation is in the same direction of ext. magnetisation field

Ex:- Manganese, Na,

3. **Ferromagnetic** Magnetic  
Strongly magnetised by extra fm



For The net magnetic moment is non-zero

### \* **Diamagnetism**

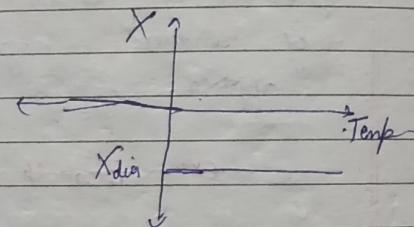
→ The magnetic susceptibility of diamagnetic substance is very small

$\chi$  is small and negative

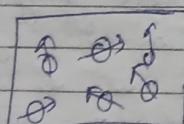
\* The relative permeability is positive and less than 1.

$$\mu_r = 1 + \chi_m$$

\* The magnetic Susceptibility of diamagnetic sub. is independent of temperature



### \* **Paramagnetism**



in absence the net magnetic moment is 0.

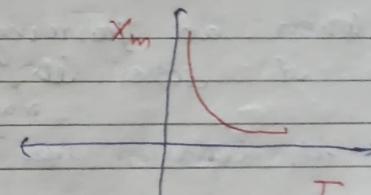
If external field intensity is increased highly then substance & temp is also then the magnetisation of paramagnetic subst approach to maximum or equals to ferromagnetic mag.  
Saturation magnetisation

\* The magnetic susceptibility of paramagnetic sub. is small & positive  
 $\chi_m$  is true & small

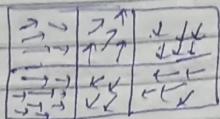
\* The relative permeability is small or slightly greater than 1.  
 $\mu_r = 1 + \chi_m$

\* The magnetic Susceptibility of paramagnetic substances varies inversely with the absolute temperature

$$\chi_m \propto \frac{1}{T} \Rightarrow \chi_m = \frac{C}{T} \rightarrow \text{Curie Constant}$$



## \* Ferromagnetism



each domain has a permanent magnetic moment.

but without applying external field the overall magnetic moment is 0 for parity. because not all the domain dipoles moment cancelled each other.

### \* On applying external field

The magnetic susceptibility  $\sigma$  is posh & large.

$$\chi = \frac{M}{H} \quad M \gg H.$$

### \* The relative permeability of ferromagnetic mat is + & large

$$\mu_r = 1 + \chi_m \quad \mu_r \gg 1$$

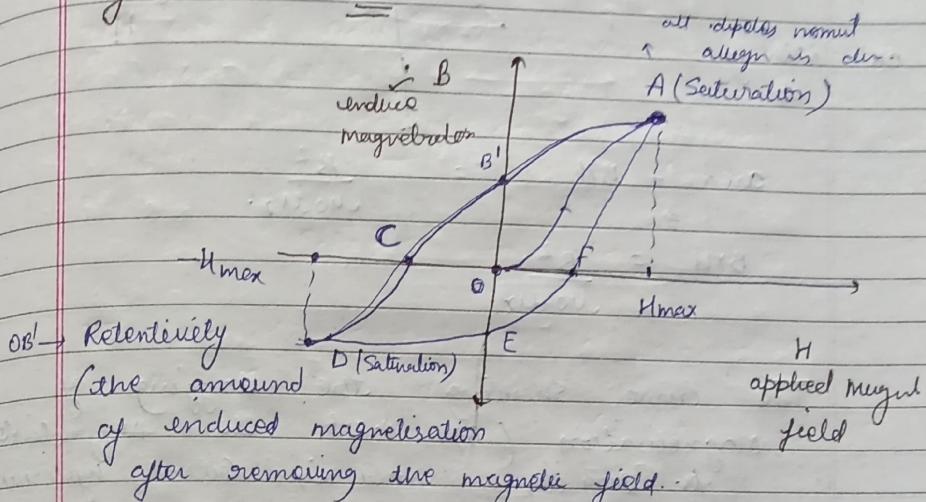
\* When an ferromag is given temperature it losses its property (no longer magnetisation)

it behave like paramagnetic substance

$$\chi_m = \frac{C}{T - T_c}$$

$\downarrow$  Curie's temperature

## Hysteresis Curve



OB → Retentivity (the amount of induced magnetization after removing the magnetic field.)

OC → Coercivity (the amount of magnetizing field for that the induced magnetization vanishes)

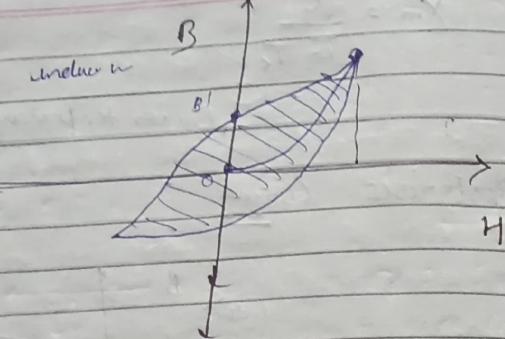
OE → Remanency

OF → Coercivity

The curve AB'C'D'EFA is called hysteresis curve

The magnetising cycle AB'C'D'EFA --

Area under  
Curves



$\mu_0 M_r$  - Reluctivity

$$\text{area} = BH = \frac{B^2}{\mu_0 M_r}$$

$$BH = \frac{B^2}{\mu_0 M_r}$$

The curve showing the lagging of magnetisation ( $B$ ) w.r.t to magnetisation for negligible field is called hysteresis curve.

Area of hysteresis curve gives the energy dissipated per unit volume of magnetisation.

Soft ferromagnetic Material

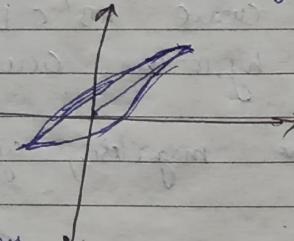
These are more sensible hence high susceptibility

have less Reluctivity

and co

Coercivity

area ↓ Energy less



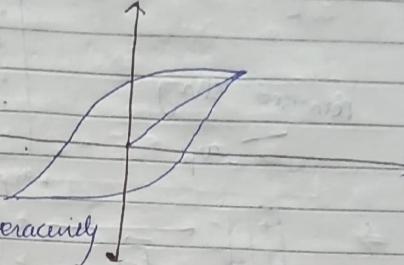
Hard ferromagnetic material

less sensible means

having less

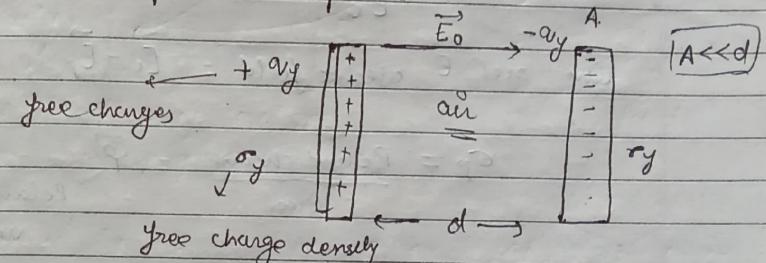
Susceptibility ↘

more Reluctivity & coercivity



# Deduce relationship between D, P & E.

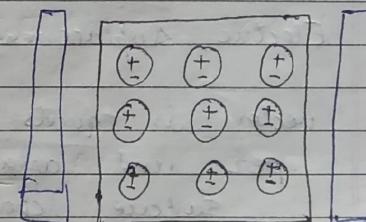
Consider a parallel capacitor

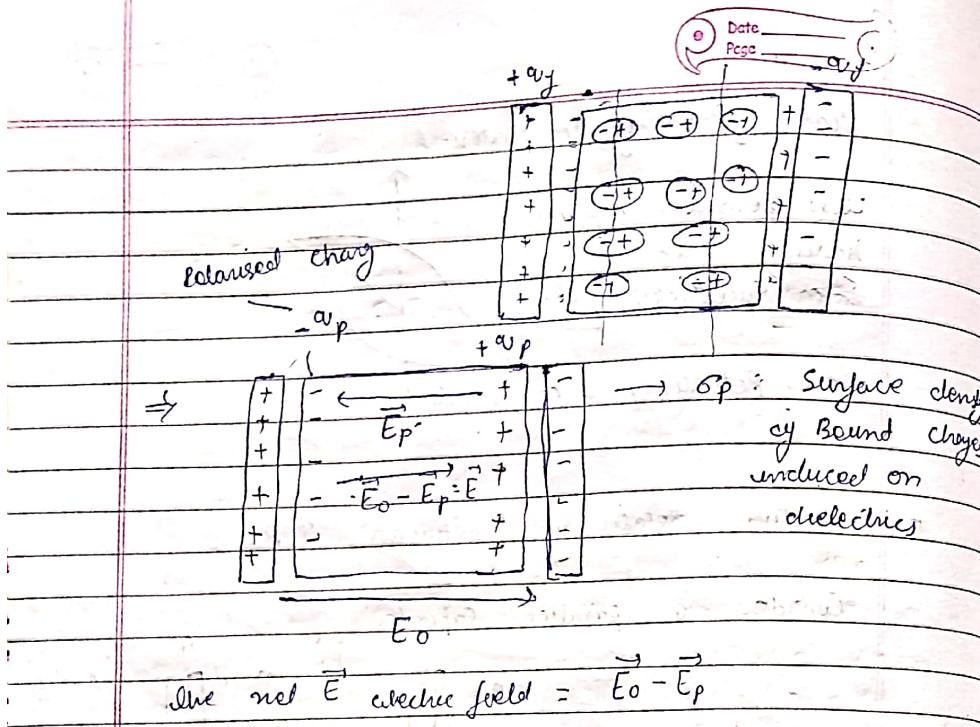


$$\sigma_y = \frac{q_y}{A}$$

Magnitude of Displacement vector  $D = \sigma_y = \frac{q_y}{A}$

On placing dielectric in II between the two plates.





$$\text{The net } \vec{E} \text{ electric field} = \vec{E}_0 - \vec{E}_p$$

$$\sigma_p = \frac{\text{Bound charge}}{\text{Area}} = \frac{\vec{P}}{\text{Area}}$$

polarisation  
vector

\* Electric field intensity :- It is the force experienced by unit positive charge placed on an electric field

$$E = \frac{F}{q}$$

SI unit N/C

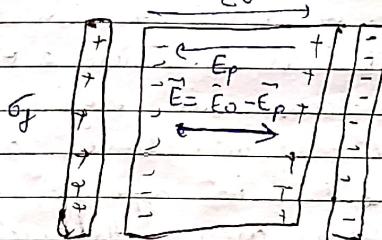
\* Electric Displacement vector ( $\vec{D}$ ) :- The magnitude of electric displacement vector is equals to free surface charge per unit area or equals to free surface charge density

$$D = \frac{q_y}{A} = \sigma_f$$

\* Polarisation vector ( $\vec{P}$ ) The magnitude of  $\vec{P}$  is equals to the bound charge per unit area or equals to surface density of bound charge

$$\vec{P} = \frac{q_p}{A} = \sigma_p \cdot c/m^2$$

Consider a II plate open can of 2 mm condenser plate each of area 'A'.



The magnitude of  $\vec{E}$  intensity at any point bw 2 plate =  $E_0 = \frac{\sigma_f}{\epsilon_0}$  by gauss law

On placing +ve then pulled 2nd -ve plate in the direction of  $\vec{E}_0$  & can -ve charge in opp direction of  $\vec{E}_0$ . As a result  $-\sigma_p$  &  $\sigma_p$  are induced.

$$E_p = \frac{\sigma_p}{\epsilon_0}$$

$$(4) \quad \sigma_p = \frac{q_p}{A} = P$$

net electric field  $E = E_0 - E_p$

$$E = \frac{\sigma_f}{\epsilon_0} - \frac{\sigma_p}{\epsilon_0}$$

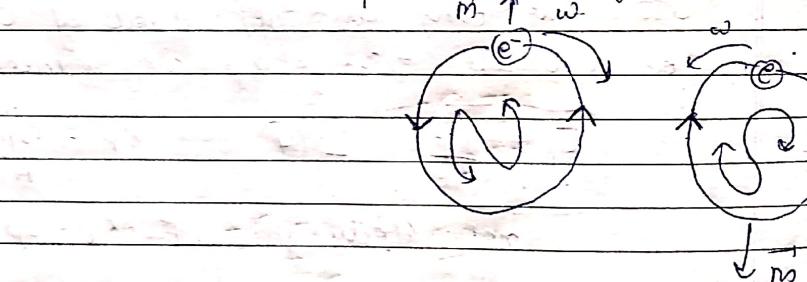
$$\epsilon_0 E = \epsilon_f - \epsilon_i$$

$$\epsilon_0 E = D - P$$

$$\boxed{D = \epsilon_0 E + P} \quad \text{hence prove}$$

### # Larmour's Theory of diamagnetism

Diamagnetic materials are those materials in which no. of electrons in the outermost shell is 2. These 2 e<sup>-</sup> revolve around the nucleus in definite path called orbit of e<sup>-</sup> with same angular velocity  $\omega$  but in opposite directions. The e<sup>-</sup> revolving around the nucleus is equivalent to tiny current loop P thereby having magnetic dipole moment  $\vec{m}$ . The magnetic dipole moment of loop 1 is directed upwards whereas that of loop 2 is directed downwards.



In absence of External mag  $\vec{B}$  the magnetic dipole moments of 2 loops being equal & opposite to each other cancel out each other so net magnetic dipole moment in absence of ext  $\vec{B}$  is 0.

⇒ In presence of External  $\vec{B}$ .

Let  $\vec{B}$  is applied perpendicular to the plane. The magnetic flux associated with loop is

$$\phi = B \cdot A = B \pi r^2 \quad (\text{A})$$

Due to changing magnetic flux in loop, an induced e.m.f is developed in the loop by Faraday's law. It is  $e$ .

$$e = -\frac{d\phi}{dt}$$

$$e = -\frac{d}{dt} B \pi r^2 = -\pi r^2 \frac{dB}{dt} \quad (\text{ii})$$

$$e = -\pi r^2 \frac{dB}{dt} \quad (\text{iii})$$

$$A \quad \vec{E} = \frac{V}{d} \frac{e}{2\pi r} \quad (\text{iv})$$

$$\vec{E} = \frac{1}{2\pi r} - \pi r^2 \frac{\partial B}{\partial t}$$

$$\vec{E} = \frac{r}{2} \frac{\partial B}{\partial t} \quad (\text{iv})$$

Due to external  $\vec{E}$   $e^-$  in orbit experience a force given by.

$$F = -e\vec{E}$$

$$ma = -e \left( -\frac{r}{2} \frac{dB}{dt} \right)$$

$$m \frac{dv}{dt} = \frac{er}{2} \frac{dB}{dt}$$

$$dv = \frac{er}{2m} dB$$

integrate both sides  $\int dv = \frac{er}{2m} \int dB$

$$V_2 - V_1 = \Delta V = \frac{erB}{2m}$$

$$\Delta V = \frac{erB}{2m}$$

The dipole moment ( $\vec{m}$ ) of current loop due to revolution of  $e^-$  is given by

$$M = IA$$

$$M = \frac{a}{T} A = -\frac{e \pi r^2}{2 \pi r} \frac{2 \pi r}{\Delta V}$$

$$M = -\frac{e \pi r^2}{2 \pi r} \cdot \frac{erB}{2m}$$

$$M = -\frac{e^2 \pi r^2 B}{2m}$$

$$n=0 \quad \frac{-e}{2} \quad m = -\frac{e^2 \pi^2 B}{4m} \quad (\text{for one orbit})$$

As there are no. of randomly oriented orbit within the atom so let  $\bar{r}$  is mean radius of all orbits then

$$\bar{r}^2 = \bar{x}^2 + \bar{y}^2 + \bar{z}^2$$

$$\bar{x} = \frac{x_1 + x_2 + \dots + x_n}{n}$$

$$\text{As } \bar{x}^2 = \bar{y}^2 = \bar{z}^2.$$

$$\bar{r}^2 = 3\bar{x}^2$$

$$\boxed{\bar{x}^2 = \frac{\bar{r}^2}{3}} \quad (10)$$

Let  $\vec{B}$  applied along z-axis

$$\vec{R}^2 = \bar{x}^2 + \bar{y}^2$$

$$R^2 = \bar{x}^2 + \bar{r}^2$$

$$\vec{R}^2 = 2\bar{x}^2$$

$$\text{from 10} \quad \boxed{\vec{R}^2 = \frac{2}{3}\bar{r}^2} \quad \text{and} \quad \vec{R}^2 = R^2$$

The total magnetic dipole of whole atom if there are  $Z$  egs in it

$$M = -\frac{Z e^2 \vec{R}^2 B}{4\pi} = -\frac{Z e^2}{3} \frac{2\bar{r}^2 B}{4\pi}$$

$$M = -\frac{Z e^2 \bar{r}^2 B}{6m}$$

If there are  $N$  no. of atoms per unit volume the dm dipole per unit volume of the substance is

$$\frac{-M}{V} = N \frac{Z e^2 \bar{r}^2 B}{6m}$$

$$\frac{M}{V} = I = \frac{1}{6} N Z e^2 \bar{r}^2 B$$

Intensity  
of magnetisation

$$\text{magnetic susceptibility} = \chi_m = \frac{I}{A} = \frac{1}{6} \frac{N e^2 Z \bar{r}^2 B}{mH}$$

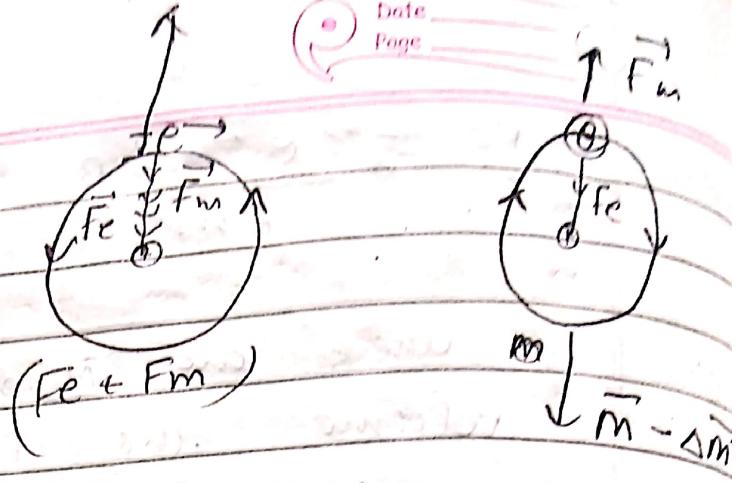
$$\mu_r = 1 + \chi_m = 1 + \frac{1}{6} \frac{N e^2 Z \bar{r}^2 B}{mH}$$

$$\text{use } B = \mu_0 H$$

$$\mu_r = 1 + \frac{1}{6} \frac{N e^2 Z \bar{r}^2 (\mu_0 H)}{mH}$$

$$\mu_r = 1 + \frac{N e^2 Z \bar{r}^2 \mu_0}{M}$$





when an external  $B$  is applied to diamagnetic atom, the  $2 e^-$  orbitals in opposite directions have different value of dipole magnetic moment & there is resultant dipole magnetic moment.

$$(\vec{m} + \Delta \vec{m}) - (\vec{m} - \Delta \vec{m}) = 2\Delta \vec{m}$$

Since - there are large no. of atoms in any given diamagnetic metal dipole magnetic moment due to all these atoms add up & net magnetisation is obtained in a direction opposite to that of applied  $B$ .

## Atomic polarisability

The lunclancy of atom's electron cloud is distorted under the influence of an external  $\vec{E}$ .

The more polarisability the easily electron cloud distorted by electric field.

## Clausius - Mossotti Relation

Cla - M - R Related the dielectric constant or dielectric relative to permittivity of a dielectric material with the polarisability of that material and the relation is given by

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

where  $N \rightarrow$  No of atoms / unit volume.

$\epsilon_r$  - Dielectric Constant

$\alpha$  - atomic polarisability

$\epsilon_0$  - free space perm.

Let  $N$  be no. of atoms / unit vol.  
of a dielectric mater.

and as we know that

The electric polarisation  $\alpha$  is directly proportional to the outer electric field.

$$P \propto E_{\text{ext}}$$

$$P = \alpha E_{\text{ext}}$$

atomic polarisability

$$\text{total polarisability} = [P = N \propto E_{\text{ext}}] \rightarrow (i)$$

also we know the:

$$P = (\epsilon_r - 1) \epsilon_0 E$$

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

$$\text{relative permittivity } \epsilon_r = \frac{\epsilon_r}{\epsilon_0} \Rightarrow \epsilon = \epsilon_r \epsilon_0$$

$$P = \epsilon E - \epsilon_0 E$$

$$P = (\epsilon - \epsilon_0) E$$

$$E = \frac{P}{\epsilon - \epsilon_0} \quad (ii)$$

As we know the relation b/w the applied field and intensity

$$\text{intensity } I = E^2 + \frac{P}{3\epsilon_0}$$

$$E_{\text{ext}} = E + \frac{P}{3\epsilon_0}$$

from eq (ii)

$$E = \frac{P}{\epsilon - \epsilon_0}$$

$$E_{\text{ext}} = \frac{P}{\epsilon - \epsilon_0} + \frac{P}{3\epsilon_0}$$

$$E_{\text{ext}} = P \left[ \frac{3\epsilon_0 + \epsilon - \epsilon_0}{3\epsilon_0(\epsilon - \epsilon_0)} \right]$$

$$E = P \left[ \frac{2\epsilon_0 + \epsilon}{3\epsilon_0(\epsilon - \epsilon_0)} \right]$$

but  $E_{\text{ext}}$  in eq (i)

$$R = N \propto P \left[ \frac{2\epsilon_0 + \epsilon}{3\epsilon_0(\epsilon - \epsilon_0)} \right]$$

$$\frac{3\epsilon_0 \epsilon - \epsilon_0}{2\epsilon_0 + \epsilon} = \frac{N}{3\epsilon_0}$$

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

$$\left[ \frac{\epsilon_r - 1}{\epsilon_r + 2} \right] = \frac{N}{3\epsilon_0}$$