Assignment-5

Ques 1:- Explain dielectric polarization in the dielectrics material. Describe the different types of polarization in a dielectric material.

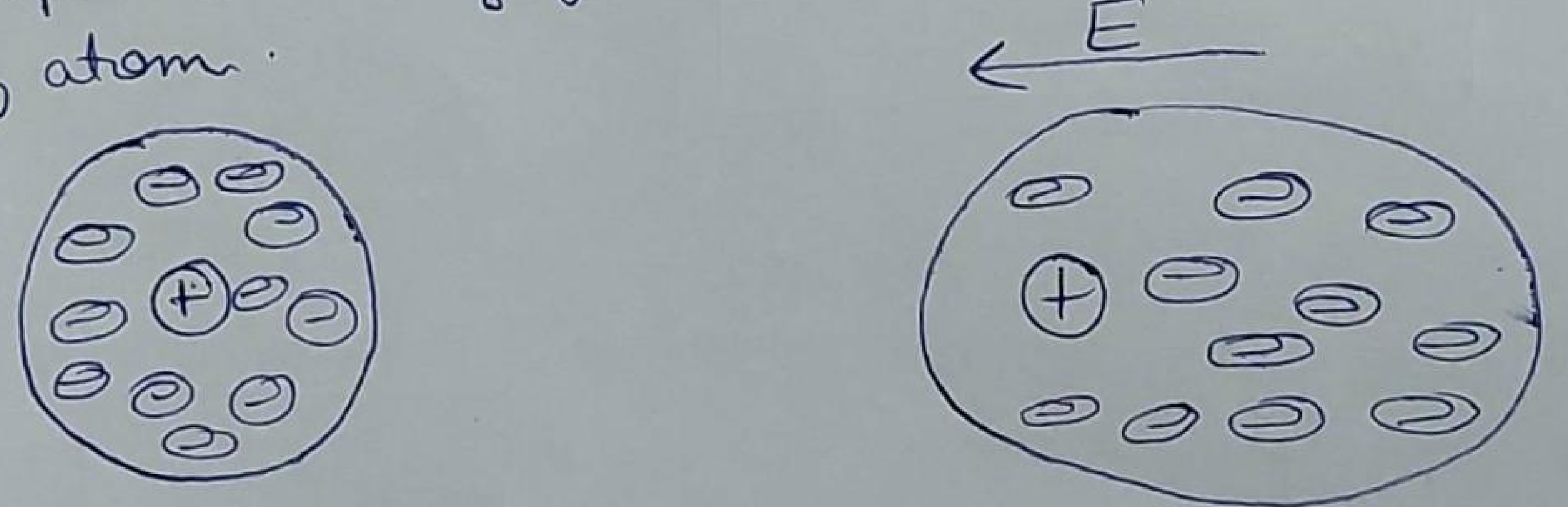
Ans "Dielectric polarization is the displacement of charge particles under the action of an electric field."

Types of polarization:-

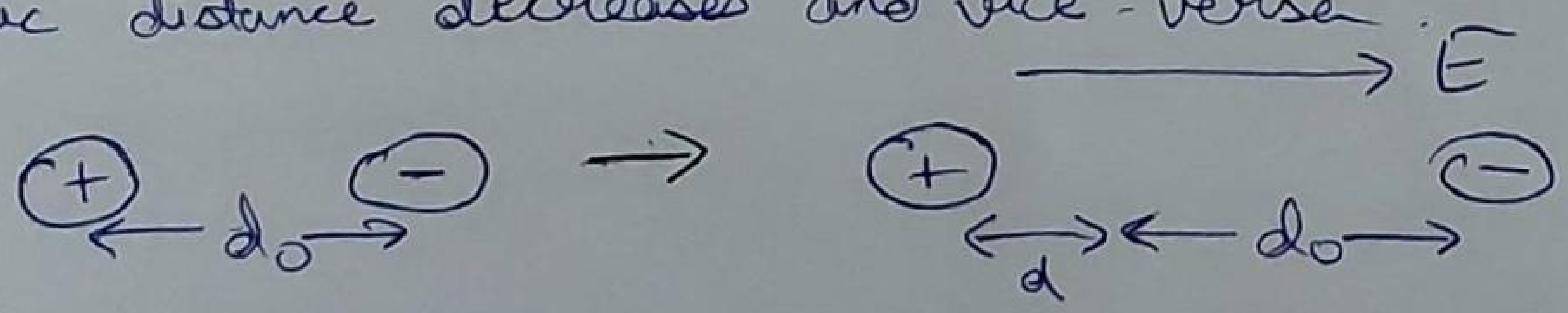
There are four important types of polarization -

1) Electronic polarization
2) Ionic polarization
3) Orientation polarization
4) Space charge polarization

1) **Electronic polarization:-** It occurs in non-polar dielectrics. In this type of polarization, the atom is unpolarized initially as the external electric field is applied, there is displacement of electron cloud of atom with respect to heavy fixed nuclei to a distance that is less that the dimension of atom.

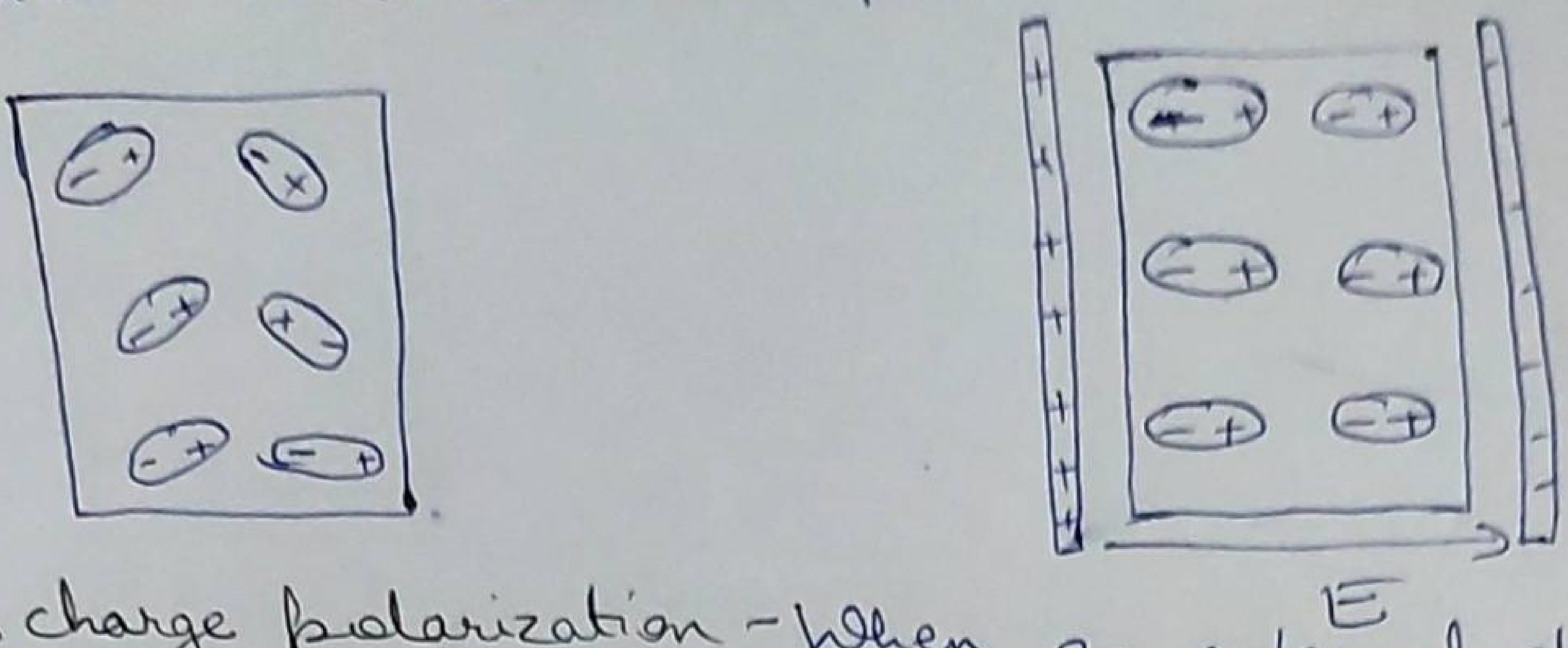


2) **Ionic polarization:-** Ionic polarisation occurs in ionic crystals. The inter ionic distance of the ions varies with the application of electric field. When applied electric field is in direction of ionic bond then inter ionic distance decreases and vice-versa.

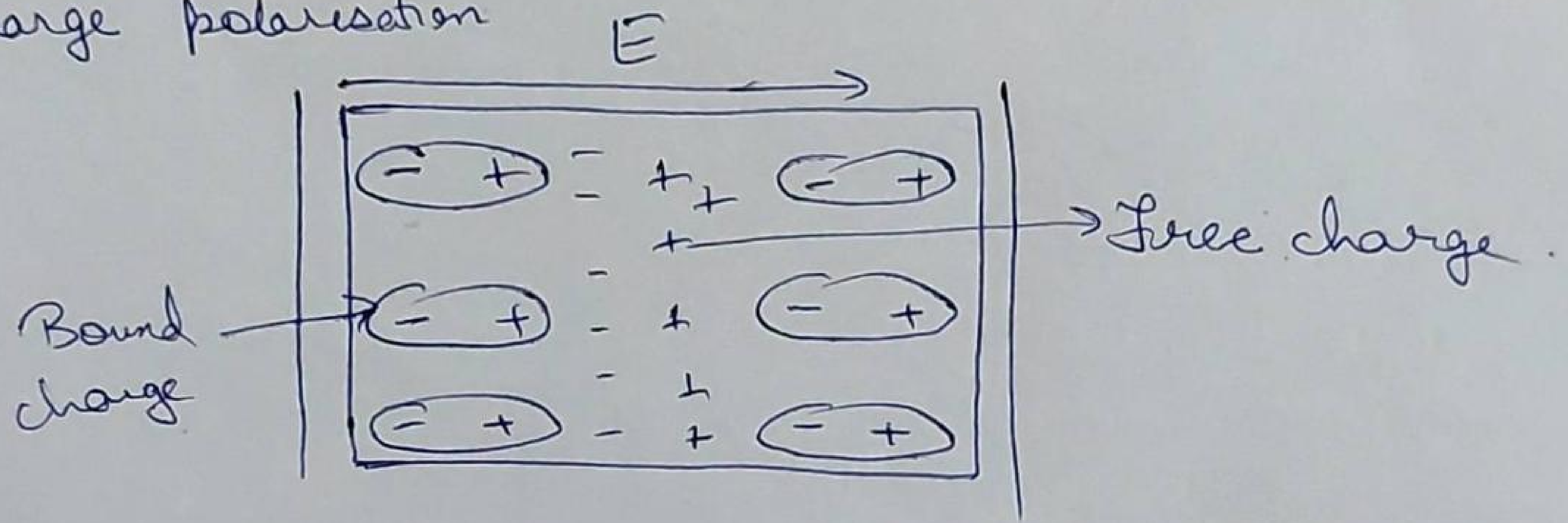


3) **Orientation Polarization** - It occurs in polar dielectrics. In absence of any electric field, the permanent dipoles are randomly oriented so that dielectric slab is electrically neutral. When an external field is applied then a torque is exerted on them to

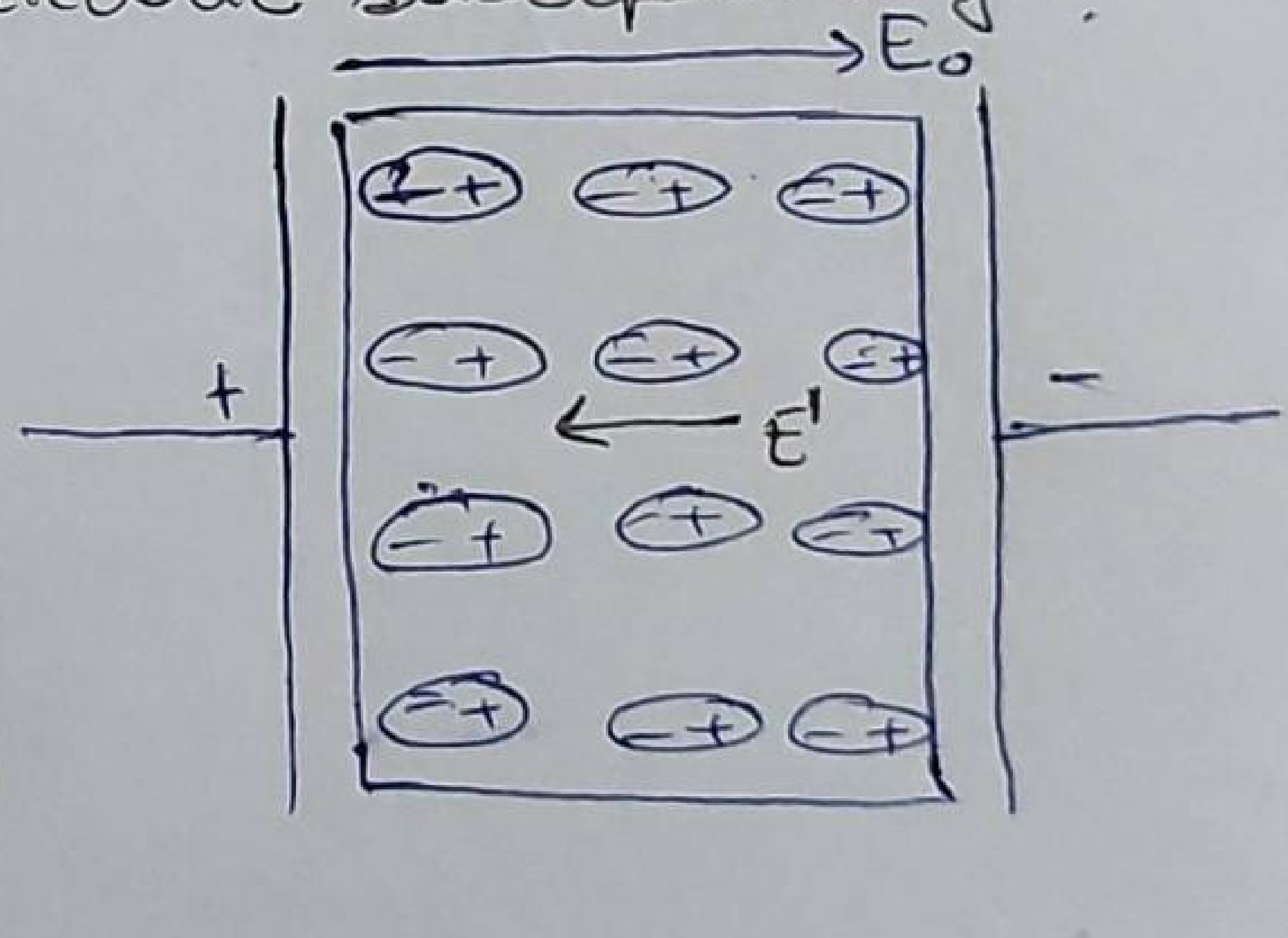
align in the direction of applied electric field E. Such type of polarization is called orientation polarization



4) Space charge polarization - When an external electric field is applied on a dielectric material the accomodation of the charges at the electrodes occurs. Therefore, there is tendency of redistribution of charge in the dielectric medium in present of applied field is known as space charge polarisation



Ques 2:- Establish the relation for $\vec{D}$, $\vec{E}$ and $\vec{P}$. What is relation between dielectric constant and dielectric susceptibility?



The effective electric field across capacitor is given by -

$$E = E_0 - E' \quad - (1)$$

$$E = \frac{\sigma}{\epsilon_0} - \frac{\sigma_p}{\epsilon_0} \quad \left[\because E = \frac{\sigma}{\epsilon_0}\right]$$

$$\epsilon_0 E = (\sigma - \sigma_p) \quad - 2$$

The dielectric displacement vector is given by -

$$D = \sigma$$

The polarization is given by $P = \sigma_p$, so.

$$\epsilon_0 E = D - P$$

$$\boxed{D = \epsilon_0 E + P}$$

Relation between dielectric constant and electrical susceptibility –

$$E = E_0 - E' \quad \text{--- (1)}$$

$$E = \frac{\sigma}{\varepsilon_0} - \frac{\sigma_P}{\varepsilon_0} \qquad \left[\because E = \frac{\sigma}{\varepsilon_0}\right]$$

$$\varepsilon_0 E = \sigma - \sigma_P$$

$$\varepsilon_0 E = (\sigma - P) \qquad [\because P = \sigma_P]$$

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

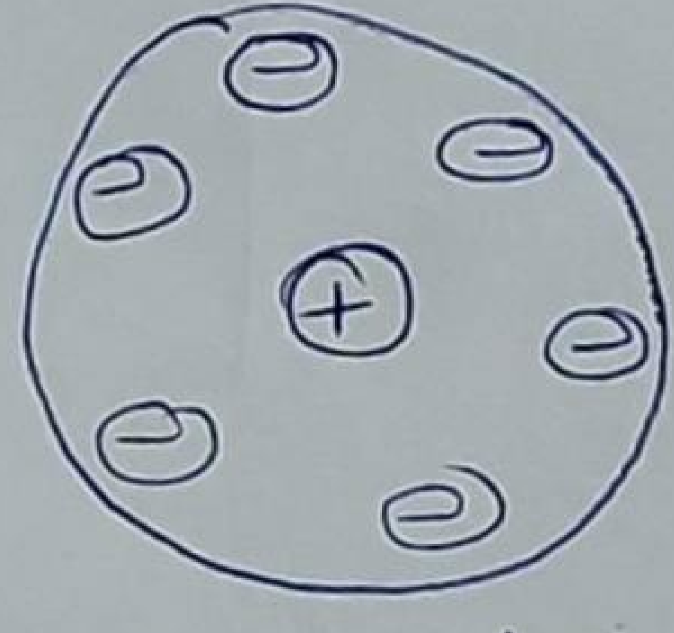
$$P = (\varepsilon_r - 1)\varepsilon_0 E \qquad (\because P = \varepsilon_0 \chi E)$$

$$\varepsilon_r - 1 = \chi$$

$$\boxed{\varepsilon_r = 1 + \chi}$$

Ques 3:- Explain polar and non-polar dielectric materials. What is dielectric strength of dielectric materials.

Ans Non-polar Dielectric Material – When center of gravity of positive and negative charges coincides in a molecule then it is known as non-polar dielectric material. It does not have permanent dipoles Eg – H_2, N_2, O_2 etc.

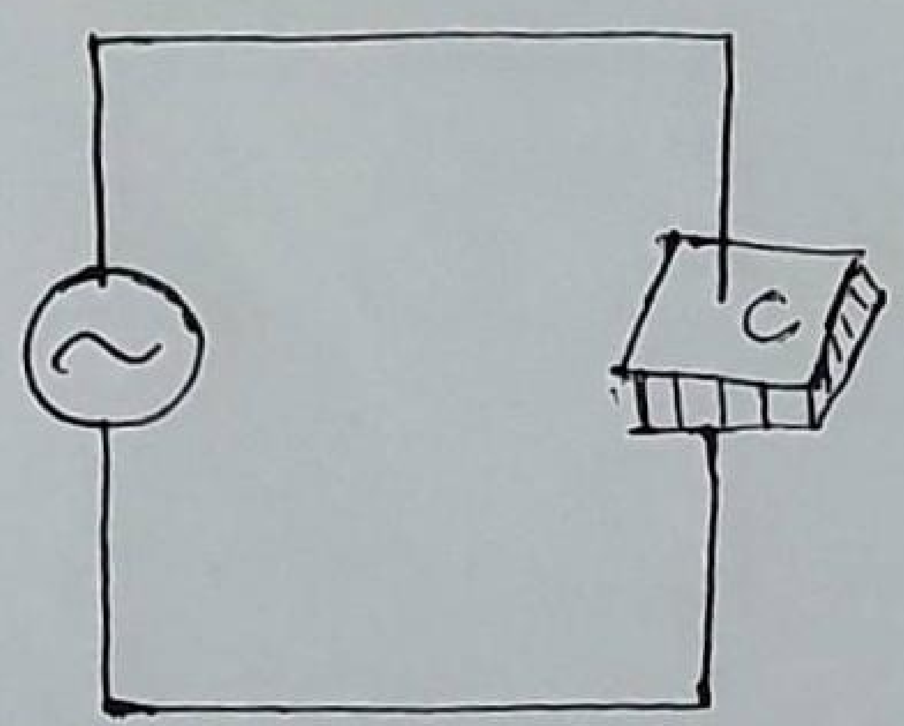


Polar dielectric material – When the center of gravity of positive charge and negative charge do not coincides then the molecule is said to be polar dielectric material. It has permanent dipoles with electric dipole moment. Eg – H_2O, HCl etc.

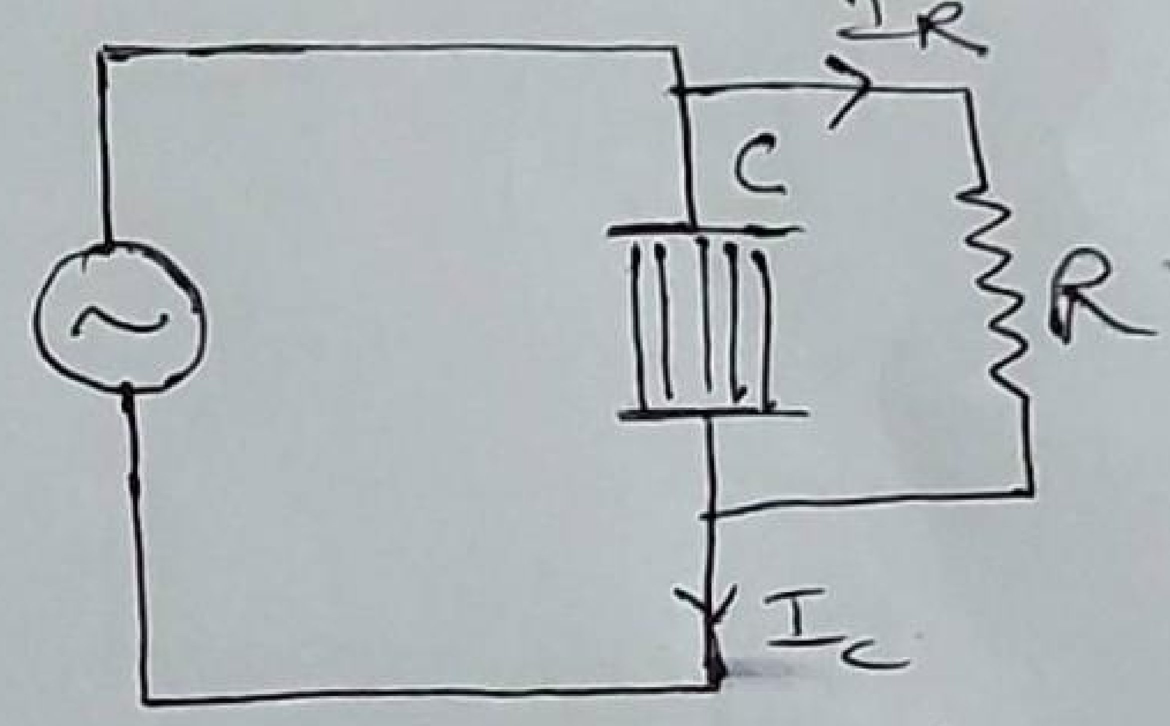
Dielectric strength:- Dielectric strength is measured as the maximum voltage required to produce a dielectric breakdown through a material.

Ques 4:- Explain the cause of dielectric loss in ac field. Deduce an expression for dielectric loss.

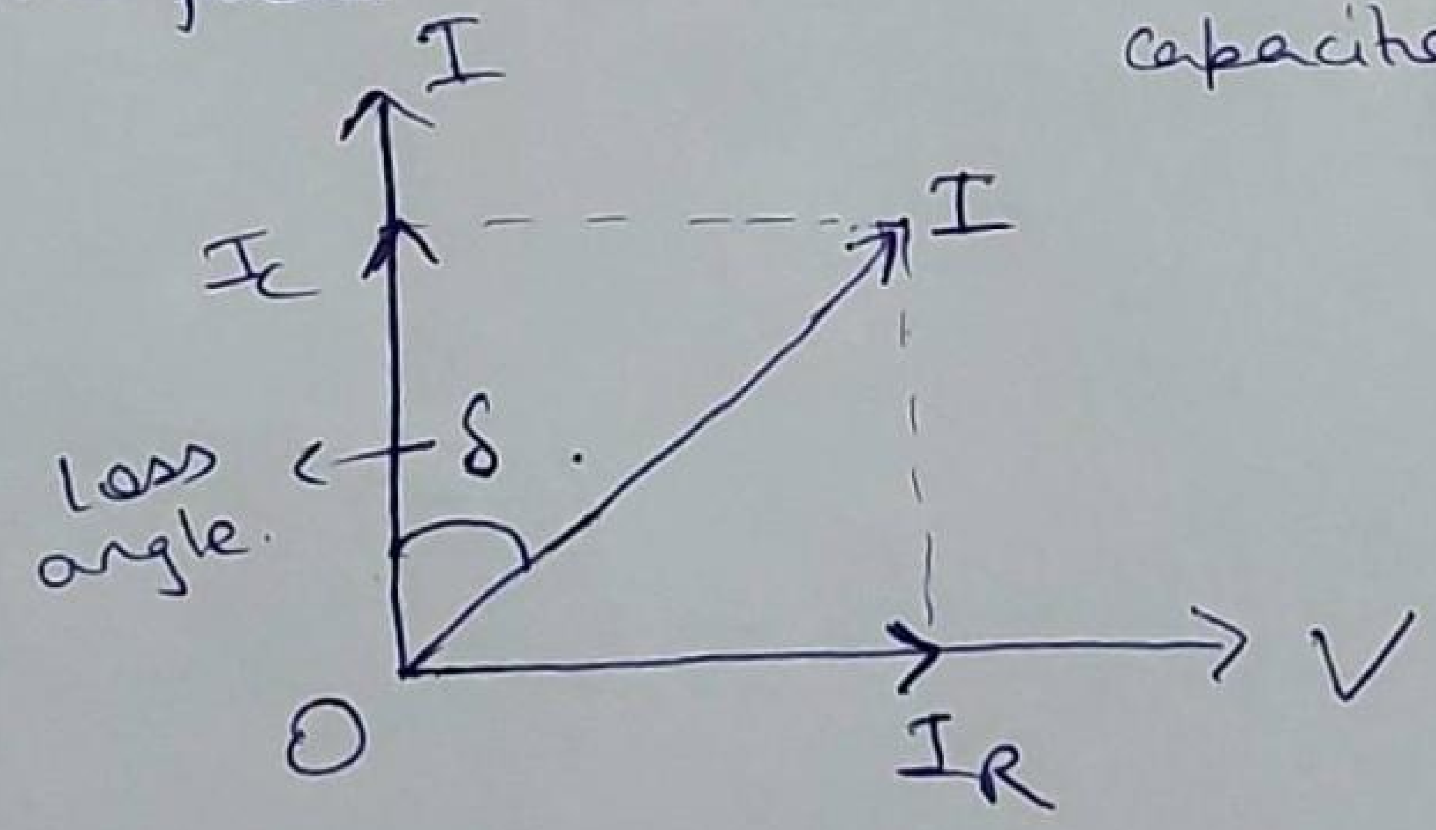
Ans Dielectric loss is the loss of energy in the form of heat by a dielectric medium due to internal friction developed in switching of dipoles to their normal state under the action of a c field.



Dielectric in ac field



A Resistance accompanying the capacitor.



Dielectric loss $= V \times I_R$ [Power loss due to resistance]

$$P = VI\cos(90-\delta)$$

$$P = VI\sin\delta \quad \text{--- (1)}$$

$$I_C = I\cos\delta.$$

$$I = \frac{I_C}{\cos\delta}.$$

From eq^n (1) we have

$$P = VI_C\frac{\sin\delta}{\cos\delta} = VI_C\tan\delta \quad \text{--- (2)}$$

$$X_c = \frac{1}{2\pi f c} \Rightarrow I_c = \frac{V}{X_c} = V(2\pi f C)$$

$$\boxed{P = V^2(2\pi f C)\tan\delta.} \quad - (3)$$

Ques 5:- Differentiate between intrinsic and extrinsic semiconductors. Deduce an expression for the densities of free electrons and holes in an intrinsic semiconductor.

Ans

Intrinsic semiconductors	Extrinsic semiconductors
(i) These are pure forms of semi-conductors, hence they do not have impurity	They are made by adding some impurity to pure form of semiconductors.
(ii) They exhibit poor electrical conductivity	The electrical conductivity is significantly high
(iii) The no. of free electrons in conduction band is equal to number of holes in valence band.	The no. of electrons and holes are not equal and depends on type of extrinsic semiconductor.
(iv) Electrical conductivity depends only on temperature.	Electrical conductivity depend on temperature as well as doping
(v) The Fermi energy levels lie in the middle of valence and conduction band	The Fermi level shifts towards the valence or conduction band
Eg - Crystalline form of pure Silicon or Germanium	Eg - Si and Ge crystals with impurity of As, P etc or In, Al etc

$$N(E) = \frac{dn}{dE}$$

$$E_f = \frac{h^2}{2m}\left(\frac{3n}{8\pi}\right)^{2/3} \Rightarrow n = \left(\frac{8\pi}{3}\right)(E_f)^{3/2}\left(\frac{2m}{h^2}\right)^{3/2}$$

$$N(E) = \frac{4\pi}{h^3}[2m]^{3/2}[E]^{1/2}$$

For e^- $\Rightarrow N(E) = \frac{4\pi}{h^3}[2m_e]^{3/2}(E - E_c)^{1/2}$

For holes $\Rightarrow N(E) = \frac{4\pi}{h^3}[2m_h]^{3/2}(E_V - E)^{1/2}$

<u>Ques 6</u>:- Prove mathematically that the Fermi level in an intrinsic semiconductor lies half way between the top of the valence band and bottom of the conduction band.

For intrinsic semiconductor

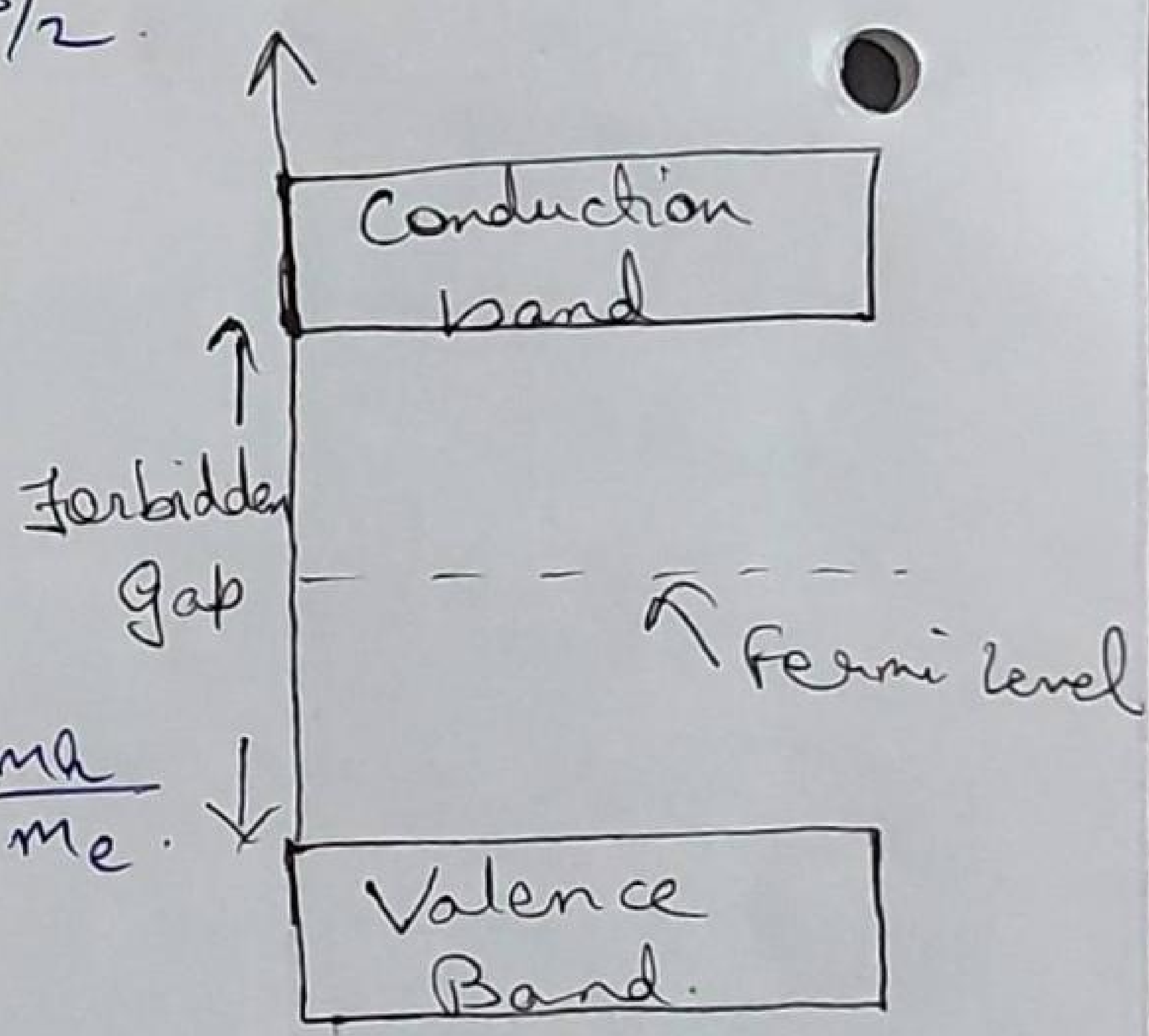
$$n_e = n_h.$$

$$2\left[\frac{2\pi m_e kT}{h^2}\right]^{3/2} \cdot e^{\frac{E_f - E_c}{kT}} = 2\left[\frac{2\pi m_h kT}{h^2}\right]^{3/2} e^{\frac{E_v - E_f}{kT}}.$$

$$m_e^{3/2} e^{\frac{E_f - E_c}{kT}} = (m_h)^{3/2} \cdot e^{\frac{E_v - E_f}{kT}}$$

$$e^{\frac{E_f - E_c - E_v + E_f}{kT}} = \left(\frac{m_h}{m_e}\right)^{3/2}.$$

$$e^{\frac{2E_f - E_c - E_v}{kT}} = \left(\frac{m_h}{m_e}\right)^{3/2}.$$



Taking log both sides.

$$\frac{2E_f - E_c - E_v}{kT} = \frac{3}{2} \log \frac{m_h}{m_e}$$

$$E_f = \frac{E_c + E_V}{2} + \frac{3}{4} kT \log \frac{m_h}{m_e}.$$

$[\because m_e = m_h]$

$$\therefore E_f = \frac{E_c + E_V}{2}.$$

Thus, Fermi energy level lies midway between conduction and valence band.

<u>Ques 7</u>:- Using mathematical expression prove that the Fermi Level lies below at bottom of conduction band and above from top of valence band in extrinsic semiconductors

For N-type

$$n_e = N_d = 2\left[\frac{2\pi m_e kT}{h^2}\right]^{3/2} \cdot e^{\frac{E_f - E_c}{kT}} \quad — (1)$$

Scanned by TapScanner

$$N_c = 2\left[\frac{2\pi m_e kT}{h^2}\right]^{3/2}$$

$$N_d = N_c \cdot e^{\frac{E_f - E_c}{kT}} \Rightarrow \frac{N_c}{N_d} = e^{-\frac{(E_f - E_c)}{kT}}$$

Taking log both sides

$$\log\left(\frac{N_c}{N_d}\right) = \frac{E_c - E_f}{kT}$$

$$\boxed{E_f = E_c - kT \log \frac{N_c}{N_d}}$$

Thus Fermi level lies below bottom of conduction band.

<u>For P - type</u>

$$n_h = N_\alpha = 2\left[\frac{2\pi m_h kT}{h^2}\right]^{3/2} \cdot e^{\frac{E_v - E_f}{kT}} \quad \text{— (1)}$$

$$N_v = 2\left[\frac{2\pi m_h kT}{h^2}\right]^{3/2}$$

$$N_\alpha = N_v \cdot e^{\frac{E_v - E_f}{kT}} \Rightarrow \frac{N_v}{N_\alpha} = e^{-\frac{(E_v - E_f)}{kT}}$$

$$\log\left(\frac{N_v}{N_\alpha}\right) = \frac{E_f - E_v}{kT}$$

$$\boxed{E_f = E_v + KT \log \frac{N_c}{N_\alpha}}$$

Thus Fermi energy level lies above top of valence band.

<u>Ques 8</u> :- Explain with necessary theory that why the properties of nanomaterials undergo a drastic change when the material is brought to nanoscale. Discuss some properties of materials that show a change at nanoscale.

Ans Reasons behind the property change at Nano-scale –

(i) Increase in Surface Area to Volume Ratio :–

The properties of materials are drastically changed at nano-scale due to increased surface area to volume ratio.

Let us consider a large sphere of radius R, volume V and surface area S then, surface area to volume ratio is given by :–

$$\frac{S}{V} = \frac{4\pi R^2}{\frac{4}{3}\pi R^3} = \frac{3}{R}.$$

This means when radius decreases from micro scale to nano-scale, the surface area to volume ratio increase drastically.

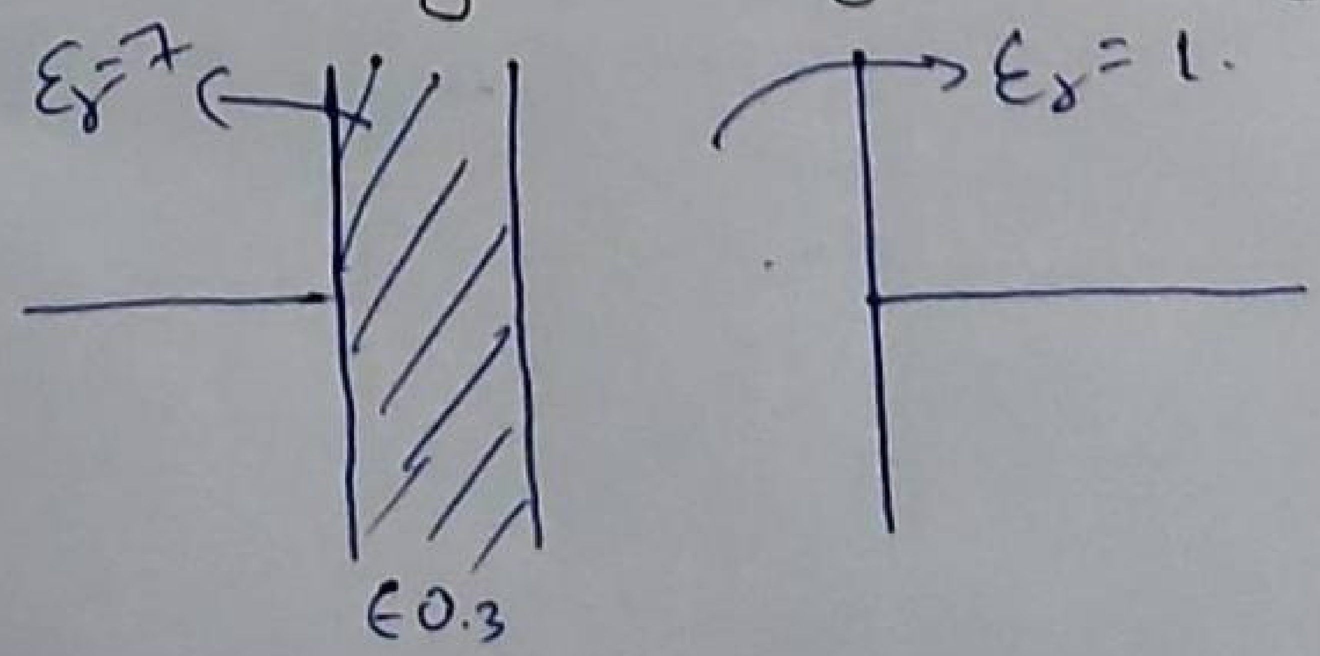
(ii) Quantum Confinement Effect :– The quantum effects begin to dominate at lower nano-scale which causes change in optical, electrical, magnetic and mechanical properties.

Some examples at nano-scale are as follows :–

(i) Opaque materials can become transparent Eg → Copper
(ii) Inert material can become catalyst Eg – Platinum
(iii) Stable material can turn combustible Eg – Aluminium.
(iv) Solids can turn into liquids at room temp. Eg – Gold.
(v) Insulator becomes conductor Eg – Silicon.

Ques 9 :– A 0.3 cm thick insulator of dielectric constant 7 is filled inside the plates, seperated by 1 cm and of area 100 cm^2 of a parallel plate capacitor. The potential diff. is 100 V. Find the value of D, E, P, Given $\varepsilon_0 = 8.9 \times 10^{-12}$ $C^2/N\text{-}m^2$

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$$



$$\frac{d}{\varepsilon_{req}\varepsilon_0 A} = \frac{d_1}{\varepsilon_{r_1}\varepsilon_0 A} + \frac{d_2}{\varepsilon_{r_2}\varepsilon_0 A}$$

$$\frac{d}{\varepsilon_{req}} = \frac{d_1}{\varepsilon_{r_1}} + \frac{d_2}{\varepsilon_{r_2}} \Rightarrow \frac{1}{\varepsilon_{req}} = \left[\frac{0.3}{7} + \frac{0.7}{1}\right]$$

$$\frac{1}{\varepsilon_{req}} = \frac{5.2}{7}$$

$$\boxed{\varepsilon_{req} = \frac{35}{26}}$$

$$E_0 = \frac{V_0}{d} = \frac{100}{0.01} = 10^4 V/m$$

$$E = \frac{E_0}{\varepsilon_{req}} = \frac{10^4}{35/26}$$

$$\boxed{E = 0.74 \times 10^4 V/m}$$

$$D = \varepsilon_0 \varepsilon_{req} E = 8.9 \times 10^{-12} \times \frac{35}{26} \times \frac{26}{35} \times 10^4$$

$$\boxed{D = 8.9 \times 10^{-8} C^2/m^2}$$

$$P = \varepsilon_0 (\chi - 1) E = 8.9 \times 10^{-12} \times \left(\frac{35}{26} - 1\right) \times \frac{26}{35} \times 10^4$$

$$\boxed{P = 2.288 \times 10^{-8} C^2/m^2}$$

Ques 10:- Find the polarization P in a dielectric material with a dielectric constant $\varepsilon_r = 2.8$ when $D = 3 \times 10^{-8} C/m^2$

$$\vec{D} = \varepsilon_r \varepsilon_0 E$$

$$E = \frac{D}{\varepsilon_r \varepsilon_0}$$

$$P = (\varepsilon_r - 1) \varepsilon_0 \overline{E}$$

$$P = (\varepsilon_r - 1) \cancel{\varepsilon_0} \frac{D}{\varepsilon_r \cancel{\varepsilon_0}}$$

Scanned by TapScanner

$$P = \frac{\varepsilon_r - 1}{\varepsilon_r} D$$

$$P = \frac{2.8 - 1}{2.8} \times 3 \times 10^{-8}$$

$$P = \frac{27}{14} \times 10^{-8} \ C/m^2$$

$$\boxed{P = 1.928 \times 10^{-8} \ C/m^2}$$