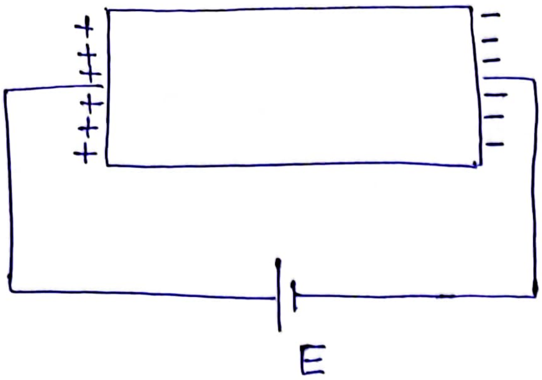
INSULATORS / DIELECTRICS



→ यदि charge किसी Body पे Uniformly distributed है तो उसका Effect हम Centre पे Consider कर सकते है।

← इस को Polarisation कहते है। यह Metal मे नही होगा क्योंकि वहा पर free Electron होते है।

$$N = \frac{n}{V_c} = \frac{N_A \rho}{A}$$

→ Insulator are generally made of PVC OR Nylon.

→ Insulation और Polarisation मे दोनो एक साथ चाहिए charge store करने के लिए Dielectrics की जरूरत होगी।

→ Non-Conducting Material do not have Sufficient free Electron to take part in Electrical Conductivity But these material have abundance of bounded Electrons due to which they get polarised on the application of Electric field.

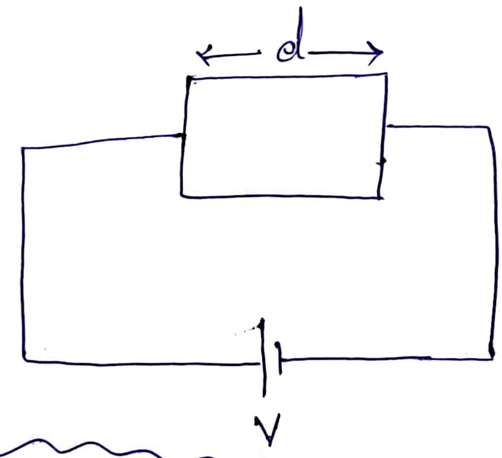
→ The Material which get Easily polarized Under the Influence of Electric field are known as Dielectrics.

→ If the main function of Non-Conducting Material is to provide Electrical Insulation then Material is known as Insulators.

→ If the main function of Non-Conducting Material is Storage Charge then it is known as Dielectrics.

Capacitance

Consider a parallel plate Capacitor.



$$C = \frac{\varepsilon_r \varepsilon_0 A}{d} = \frac{\varepsilon A}{d}$$

C → Capacitance (in Farad)
A → Cross Section area of the plates
d → Distance b/w the plates
ε_0 → Permittivity of free Space or Vaccum
$\varepsilon_0 = 8.854 \times 10^{-12}$ F/M

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

ε_r = Relative permittivity OR Dielectric Constant of Material.

ε = Permittivity of Material $\Rightarrow \varepsilon = \varepsilon_r \varepsilon_0$

# Material	ε_r
Vacuum	1
Air	1.0006
Helium	1.0000684
paper	2.0 — 3.0
Teflon	2.1
Fused Quartz	3.8
Nylon	3.5
Bakelite	4.9
Mica	6
Distilled Water	81
TiO_2	100

→ For a Capacitor

$$Q \propto V$$

$$Q = CV$$

→ Energy stored in a Capacitor

$$W = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}Q \cdot V$$

→ Energy Density

→ Energy stored per Unit Volume.

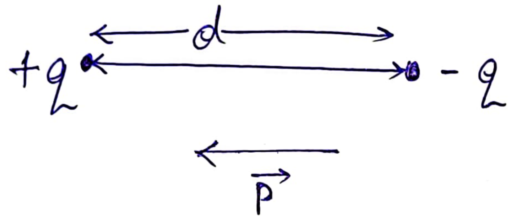
$$D = \varepsilon E$$

D → Electric flux density (C/m^2)
E → Electric field Intensity (V/m)

$$\varepsilon = \frac{D}{E}$$

Electric dipole Moment. ($\vec{p}$) (GS के Page 75)

→ To Equal and opposite charges separated by certain distance Constitute on Electric dipole.



Electric dipole Moment ($\vec{p}$)

$$\vec{p} = q \cdot \vec{d}$$

Unit → ① C-m
② Debye

$$1 \text{ Debye} = 3.33 \times 10^{-30} \text{ C-m}$$

$\vec{p}$ → It is a vector Quantity and Vector direction is taken from negative charge to positive charge.

→ अगर Atomic no. पे stable है तो Atom
→ अगर Molecule no. पे stable है तो Molecule

Polarisation ($\vec{P}$) (GS के Page-76)

→ It is defined as Electric dipole moment per Unit Volume.

$$\vec{P} = \frac{\text{Electric dipole Moment}}{\text{Volume}}$$

On a Macro-Scopic Scale

N → No. of Electric dipole per Unit Volume.
$\vec{p}$ → Electric dipole moment of Each dipole.

Then

$$\vec{P} = \vec{p} + \vec{p} + \text{---} \quad N \text{ times}$$

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

(Acc. to GS part)

N → No. of Molecules per Unit Volume

N·ΔV → No. of Molecules in Volume ΔV.

$$\vec{P} = \frac{1}{\Delta V} \sum_{j=1}^{N \cdot \Delta V} \vec{p}_j = N\vec{p}$$

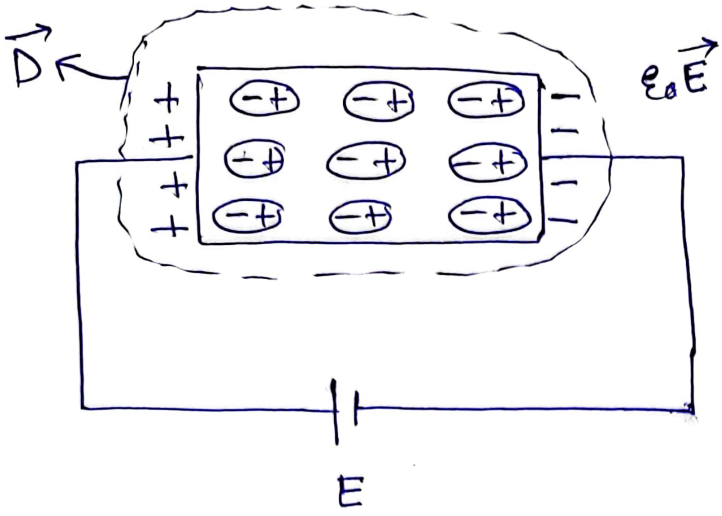
$\vec{p}$ → Electric dipole Moment of Each Molecule

Unit of $\vec{P}$:-

$$= \frac{1}{m^3} \times C\text{-}m$$

$$= \frac{C}{m^2}$$

⑧



→ Total Electric flux density in a dielectric material is due to

① → Applied Electric field $(\varepsilon_0 \vec{E})$

② → Polarisation Inside the Material $(\vec{P})$.

i.e., $\vec{D} = \varepsilon_0 \vec{E} + \vec{P}$ — ① (Acc to Material Science)

but $\vec{D} = \varepsilon_r \varepsilon_0 \vec{E}$ — ② (Acc. to Physics)

from Eqⁿ(1) & Eqⁿ(2)

$$\vec{P} + \varepsilon_0 \vec{E} = \varepsilon_r \varepsilon_0 \vec{E}$$

$$P = \varepsilon_r \varepsilon_0 \vec{E} - \varepsilon_0 \vec{E}$$

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

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

where

$\chi_e = \varepsilon_r - 1$

↳ Electric Susceptibility of Material

$$\chi_e = \frac{P}{\varepsilon_0 \vec{E}} = \frac{\text{Bound charge density}}{\text{Free charge density}}$$

Polarizability (α)

For unit dipole,

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

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

$$\alpha = \frac{p}{E}$$

↓

Polarizability   mean → ability (जगह के अनुसार अपने आप को ढाल लेना)

→ It measure Electric Pliability of the particle that is average Electric dipole Moment per Unit applied Electric field strength.

→ Unit of α

$$= \frac{C\text{-}m}{V/m} = \frac{Cm^2}{V}$$

$$= \text{Farad} \times m^2 \qquad \because \text{Farad} = \frac{C}{V}$$

We have

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

but $\vec{p} = \alpha\vec{E}$

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

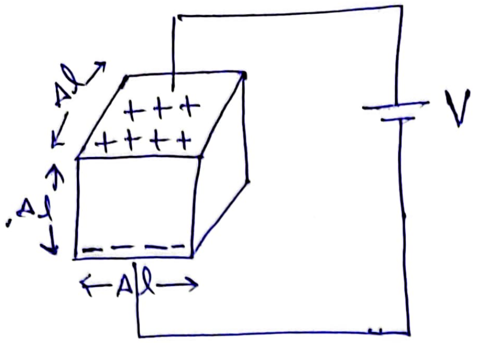
but $\vec{P} = \varepsilon_0 \chi_e \vec{E}$

$$\therefore \varepsilon_0 \chi_e \vec{E} = N\alpha\vec{E}$$

$$\alpha = \frac{\varepsilon_0 \chi_e}{N} = \frac{\varepsilon_0(\varepsilon_r - 1)}{N}$$

(10)

Energy density in Capacitor



$$C = \frac{\varepsilon A}{d}$$

$$C = \frac{\varepsilon \cdot (A l)^2}{A l}$$

$$C = \varepsilon A l$$

$$E = \frac{V}{A l}$$

$$V = E \cdot A l$$

Energy stored in a Capacitor

$$W = \frac{1}{2} C V^2$$

$$W = \frac{1}{2} \cdot \varepsilon \cdot A l \cdot E^2 \cdot (A l)^2$$

$$w = \frac{W}{A l^3} = \frac{1}{2} \varepsilon E^2$$

$$w = \frac{1}{2} \varepsilon E^2$$

↑ Energy density → Energy stored per unit volume.

$$w = \frac{1}{2} \varepsilon E^2$$

$$w = \frac{1}{2} \varepsilon_r \varepsilon_0 \vec{E} \cdot \vec{E}$$

$$w = \frac{1}{2} \vec{D} \cdot \vec{E}$$

$$w = \frac{1}{2} (\varepsilon_0 \vec{E} + \vec{P}) \vec{E}$$

$$w = \frac{1}{2} \varepsilon_0 E^2 + \frac{1}{2} \vec{P} \cdot \vec{E}$$

($\frac{1}{2} \vec{P} \cdot \vec{E}$ →) Additional Energy density in dielectric material.

Dielectric Strength

→ Dielectric strength is the maximum Electric field Intensity that a dielectric material can sustain without breakdown.

→ It is the defined as minimum voltage per unit thickness required to cause breakdown in the material.

⇒ Unit : KV/mm OR MV/m

Material	Dielectric Strength (MV/m)
Air	3
Mineral Oil	15
Impregnated paper	15
Polystyrene	20
Rubber	21
Bakelite	25
Glass	30
Mica	200

Mechanism of Polarization (GS के Page 77)

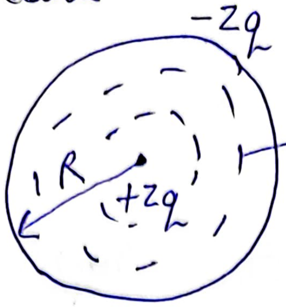
→ There are four mechanism of Polarization

① → Electronic OR Induced Polarization
② → Ionic OR Molecular Polarization
③ → Orientational Polarization
④ → Interfacial OR Space charge Polarization.

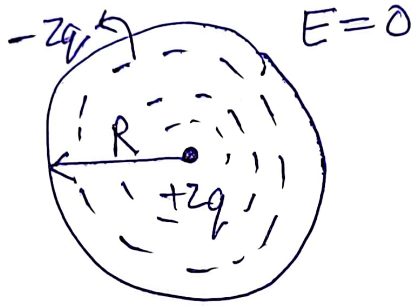
① Electronic Polarization.

→ Consider a simple model of Atom having $+zq$ charge in the Nucleus and $-zq$ charge uniformly distributed in a spherical volume of radius R.

Z → Atomic no. of Element
R → Atomic Radius



→ In the absence of electric field positive charge (+Zq) is situated at the Centre of Electron Cloud, hence no dipole is formed.

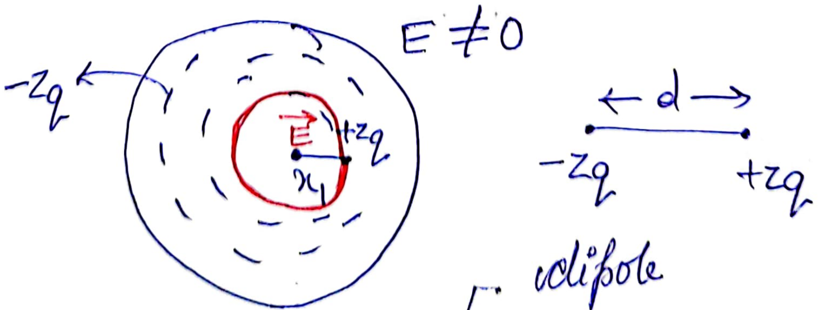


⇒ No dipole

$p = 0$

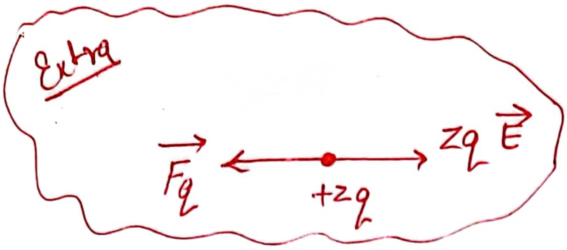
→ Let Electron Cloud is Spherical

→ On the Application of electric field Centre of Electron Cloud and Nucleus are separated by a distance 'x'
(Electron Cloud is assumed to remain Spherical).



dipole
↳ $p_{Induced} = (Zq)x$

$Q\vec{E} = +Zq\vec{E}$



→ Under Equilibrium the net force Experienced by Nucleus is due to

① force due to applied Electric field $(+zq\vec{E})$

② Coulombic attraction force due to charge Enclosed in sphere of radius 'x' $(\vec{F_q})$

So,

$$\vec{F}_{net} = \vec{F_q} + Zq\vec{E}$$

Charge Enclosed in Sphere of radius

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

q (small q) → magnitude of Electron charge $= 1.6\times10^{-19}C = e$

Now

$$\vec{F}_{net} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{\left(\frac{-Zq\,x^3}{R^3}\right)(+Zq)}{x^2}$$

$$\boxed{\vec{F_q} = -\frac{1}{4\pi\varepsilon_0}(Zq)^2 \cdot \frac{x}{R^3}}$$