Nano Science :-

The word Nano means small and $1nm = 10^{-9}m$. Therefore 1nm is used to measure things that are very small such as atoms and molecules.
for example → Hydrogen atom is 0.1nm in size, Red Blood cells are 500nm in size and wavelength of visible colours is 400-700 nm etc.

Nanoscience → To study about the materials which are at nanoscales.

Nanotechnology → To prepare the materials to bring them at nanoscale.

When we go to nano scale, the interaction and the physics between the atoms display properties which are diff. from those at larger scale. The Bulk properties of any materials are nearly average of all quantum forces affecting all the atoms as we make this smaller and smaller we finally reached to the point where averaging no longer force. The effect does not occur when we go from ~~a~~ macro to micro dimensions but it becomes dominant when nanometer size is achieved.

The properties of materials are found to be different for two main reasons:-

1. Surface Area to volume ratio.
2. Quantum confinement effect.

① **Surface area to volume ratio:-**

ex-) In case of sphere:-

$S.A. = 4\pi r^2 \quad V = \frac{4}{3}\pi r^3$

$$\frac{S.A.}{V} = \frac{3}{r}$$

∴ The properties are changed.

② **Quantum confinement effect:-**

As we have already study particle in a box as well as in a potential box. when the dimensions of such well or box are of the order of de-broglie wavelength of electrons or mean free path of electrons (i.e. within few tens of nano meters) energy level of electrons gets changed this effect is called quantum confinement effect.

The properties which are found to changed because of above two major reasons are as follows:-

1. opaque substance can becomes transparent. ex-) copper.

② Inert materials can becomes catalyst
ex→ Platinum.

③ Stable materials can turn combustible.
ex→ Aluminium.

④ Solids can turn into liquids at room temp. ex→ Gold

⑤ Insulators can becomes conductors.
ex→ Silicon.

Properties of Nano materials :-

The following are the properties of Nano materials :-

→ They are hard.
→ They are exceptionally Strong.
→ They are ductile at high temp.
→ They are chemically very active.
→ They are corrosion Resistance.

Few more properties of are given in tabular form :-

Properties	Examples
Catalytic	Better catalytic efficient through higher surface to volume ratio.
Electrical	Increase electrical conductivity in ceremics and magnetic Properties.
Magnetic	Increases the magnetic coercivity upto critical

super magnetic behaviour

Mechanical	Improves the hardness and toughness of the metals and alloys.
Optical	Spectrum of optical absorption and fluorescence properties increases quantum efficiency of semiconductor crystals.
Biological	Increases permeability through biological barriers (membranes biocompatibility

Dielectrics :-

Dielectrics are basically the electric insulators which do not contain free electrons or the number of free e^- are too low to constitute the electric current. In dielectrics are tightly bound to the nucleus of the atom. Examples are Rubber, glass, mica, plastic, etc. When a non conducting material like a dielectric is placed in an external electric field. It modifies the field. Now it acts as a charge storage device. Therefore, when a charge storage device is main function of the material it is known as dielectric. In practice it has been found that dielectric materials can conduct an electric current to an

The insulators however offer no electric current through them. Dielectric helps in maintaining in following three ways:-

(i) It maintains small seperation between two large plates in a capacitor.
(ii) It decreases the potential difference.
(iii) It increases the capacitance of a capacitor.

Mathematically, dielectric constant may be defined as:

$$K = \frac{C}{C_0}$$

C → (capacitance ~~in~~ filled inside the plate)

C_0 → (capacitance when air is filled b/w the plates).

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

$\boxed{K = \epsilon_r}$ The dielectric materials are divided into two categories:-

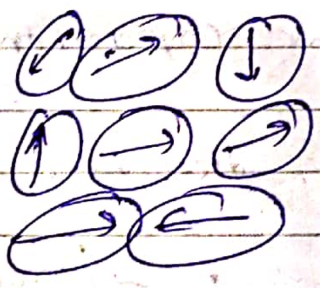
(i) Polar dielectrics.

(ii) Non polar dielectrics.

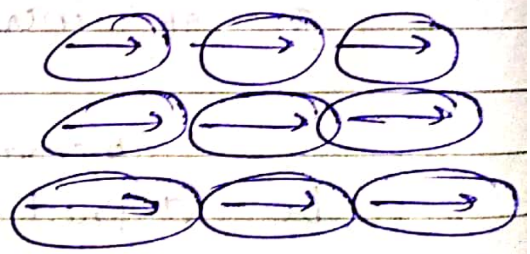
Polar dielectrics:-

If the centre of gravity of positive and negative charges in a molecule are seperated by a short distance (10^{-10} m) then the molecule is called polar molecule. As a Result, it behaves as a dipole with its dipole moment directed along a line joining +ve and -ve charges. Dielectric containing such molecules are known as polar dielectrics. In the absence of external electric field, the net dipole moment is zero because random orientation of dipoles inside the material.

Ex:- CO, NH_3, N_2O, H_2O, etc.



(absence of Electric field).



(presence of external electric field).

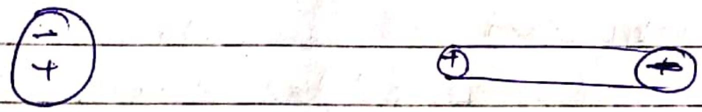
Non-polar dielectrics:-

In case of non-polar

dielectrics centre of gravity of +ve and -ve charges in a molecule coincides as a Result these molecules do not have any permanent dipole moment. Dielectrics containing such molecules are known as non-polar dielectrics. In these dielectrics net dipole moment is 0.

Examples are O_2, N_2, H_2, etc.

But non polar dielectrics are subjected to an external electric field. The seperation of -ve and +ve charges gets displaced by a distance of 10^{-10} m. As a Result it behaves like a dipole and the dielectric is said to have been polarised.



When dielectric is placed in electric field its molecules becomes. electric dipoles and the dipoles is said to have been polarized. The induced dipole moment per unit volume is called electric or dielectric polarization. Represented by $\vec{P}$.

Experimentally it has been found that electric dipole moment P_m induced in each molecule is supposed to the electric field E_m

$$\vec{P_m} \propto \vec{E_m}$$

$$\vec{P_m} = \alpha \vec{E_m}$$

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If there are N molecules per unit volume then the total induced electric dipole moment per unit volume.

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

$$\boxed{\vec{P} = N\alpha \vec{E}_m}$$

Electric displacement vector ($\vec{D}$):-

The electric field $\vec{E}$ around a charge q at a point is:-

$$\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{q\vec{r}}{r^3} \rightarrow (1)$$

We also know that the charge per unit area or electric displacement ($\vec{D}$) at any point

Since the displacement depends upon the direction of the area. Therefore, the electric displacement should be the vector quantity and direction is being taken as the direction to the normal to the surface.

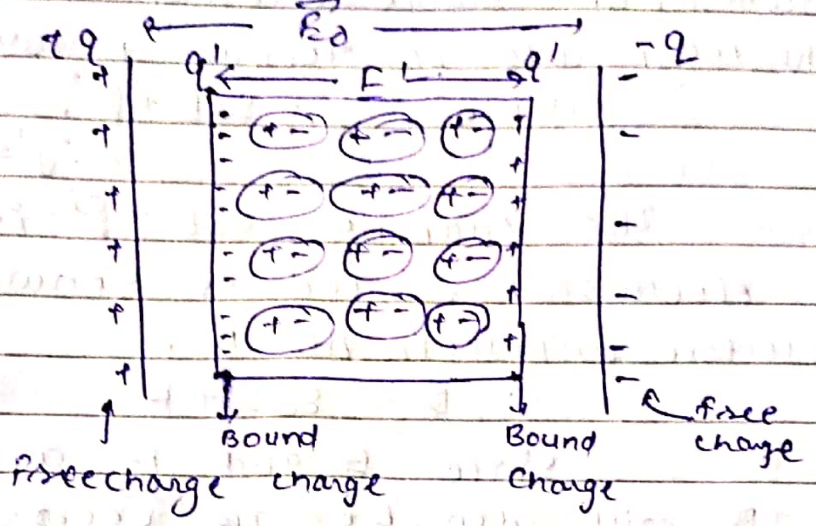
$$\vec{D} = \frac{1}{4\pi} \frac{q\vec{r}}{r^3} \rightarrow (2)$$

Since from eq (1) and (2) on equating gives:-

$$\vec{D} = \epsilon \vec{E}$$

where $\vec{D}$ and $\vec{E}$ have same directions.

Behaviour of Dielectric bar in Electric field:-



Net field $\vec{E} = \vec{E_0} - E'$

Relation between $\vec{E}$, $\vec{D}$ and $\vec{P}$:- (as above). (same fig.)

Let σ be the surface charge density of free charges on the capacitor plate σ' be the charge density due to induced charges on the dielectric within the capacitor plate.

The electric field within the plate due to σ and σ' are :-

$$E_0 = \frac{\sigma}{\varepsilon_0} , \quad E' = \frac{\sigma'}{\varepsilon_0}$$

These are oppositely charged.

The magnitude of the Resultant field:-

$$\vec{E} = \vec{E_0} - \vec{E'}$$

$$= \frac{\sigma}{\varepsilon_0} - \frac{\sigma'}{\varepsilon_0} = \frac{1}{\varepsilon_0}\left[\sigma - \sigma'\right]$$

$$\varepsilon_0 E = \sigma - \sigma'$$

$$\sigma = \varepsilon_0 E + \sigma'$$

The induced charge density or polarisation charge density ρ' is equal to the magnitude of electric polarisation.

Therefore $\rho = \varepsilon_0 E + \rho'$.

$\because \rho' = P$

The quantity $\varepsilon_0 E + P$ is significant in electrostatics and is known as electric displacement D.

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

Since E and P are vectors $\therefore$ D will also be a vector quantity.

$$\boxed{\vec{D} = \varepsilon_0 \vec{E} + \vec{P}}$$

Relation between $\vec{P}$ and K :-

If E_0 is the electric field b/w the plates of capacitor filled with air and E' be the induced field in the capacitor. Then the resultant field within the dielectric is given by :-

$$\vec{E} = \vec{E_0} - E'$$

$$\vec{E'} = \frac{\rho'}{\varepsilon_0} = \frac{\vec{P}}{\varepsilon_0}$$

$$\vec{E} = \vec{E_0} - \frac{\vec{P}}{\varepsilon_0}$$

$$\vec{P} = \varepsilon_0 \vec{E_0} - \varepsilon_0 \vec{E}$$

$$\vec{P} = \varepsilon_0 (\vec{E_0} - \vec{E})$$

$$\vec{P} = \frac{\varepsilon_0}{\vec{E_0}} \left(\frac{\vec{E_0}}{E} - 1\right)$$

$$P = \varepsilon_0 E\,(K-1)$$

where K is the dielectric constant of the material.

This indicates that in free space. (K = 1) . This gives P = 0 .

In terms of Relative permittivity above relation can also be written as:-

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

Relation between electric susceptibility and dielectric constant:-

Electric susceptibility is defined as ratio of electric polarisation to the electric field.

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

$$\vec{P} = \vec{E}\,\chi_e \rightarrow (1)$$

$$\vec{D} = \varepsilon_0 \vec{E} + \vec{P} \rightarrow (2)$$

where $\varepsilon_0 \rightarrow$ permittivity of free space

we also know that:-

$$D = \varepsilon \vec{E} \rightarrow (3)$$

where $\varepsilon \rightarrow$ absolute permittivity.

Now on substituting the value of P:-

$$\varepsilon \vec{E} = \varepsilon_0 \vec{E} + \chi_e \vec{E}$$

$$\varepsilon = \varepsilon_0 + \chi_e$$

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$$\frac{\epsilon}{\epsilon_0} = 1 + \frac{\chi_e}{\epsilon_0}$$

$$K = 1 + \frac{\chi_e}{\epsilon_0}$$

$$\epsilon_r = 1 + \frac{\chi_e}{\epsilon_0}$$

$$\boxed{\chi_e = (\epsilon_r - 1)\,\epsilon_0}$$

Dielectric Strength :-

It is the maximum electric field that the dielectric can maintain without breakdown. When we apply external electric field on dielectric upto certain stage it behaves like dielectric. Thereafter if we increase the electric field it behaves like a conductor. Hence dielectric strength is nothing but critical value of electric field below which it behaves like a dielectric and above which it behaves like a conductor.

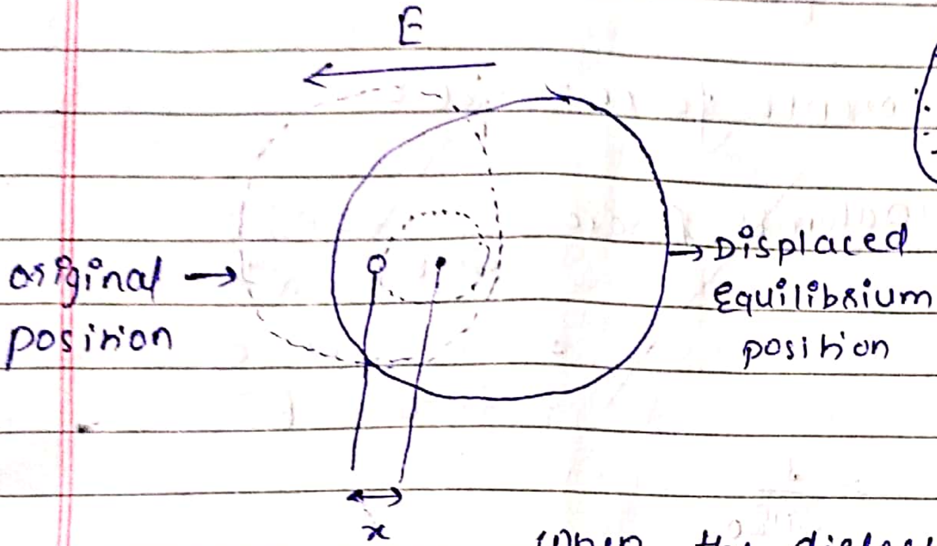
Types of Polarisation :-

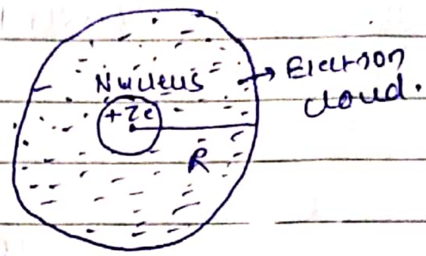
There are four different mechanism by which electric polarisation can occur when they are subjected to external electric field :-

(i) Electronic polarisation.
(ii) Ionic Polarisation.
(iii) Orientational polarisation.

(iv) Space charge polarisation.

Electronic polarization:-





When the dielectric is placed in external electric field, there is displacement ~~of~~ in the electron cloud relative to the nucleus forming the atoms of the molecules. As shown in the above fig.

Consider the nucleus of an atom is surrounded by electron cloud of charge $-Ze$ distributed in the sphere of radius R. The charge density is given by :-

$$\delta = \frac{\text{charge}}{\text{volume}} = \frac{(-Ze)}{\frac{4}{3}\pi R^3} = -\frac{3}{4}\frac{Ze}{\pi R^3}$$

When an electric field is applied to this atom the nucleus and electron experience ie Lorentz force of magnitude:-

$$qE = ZeE$$

Therefore in opposite direction, the nucleus and electron are pulled apart As a result Coulomb's forces begins to start which tends to oppose the displacement. The equilibrium position is acheived when Coulomb's force and Lorentz force becomes equal.

Lorentz force $= -Ze\,E$

Coulomb's force $= \frac{1}{4\pi\varepsilon_0} \frac{(Ze)\,e}{R^2}$

$= \frac{1}{4\pi\varepsilon_0} \cdot \frac{(Ze)\,e}{R^2}$

$= \frac{1}{4\pi\varepsilon_0}$