DEPART OF ELECTRONICS AND COMMUNICATION ENGINEERING

19EC402 – ELCTROMAGNETIC FIELDS

UNIT – II DIELECTRICS AND STATIC ELECTRIC CURRENT

Dielectrics

Differences between dielectrics and conductors.

S.No.	Dielectrics	Conductors
1.	Dielectric does not contain free electrons.	In conductors each atom contains at least one free electron.
2.	All the electrons are tightly bound to the nucleus of the atom.	The electrons in the outer most orbit are loosely bound by the nucleus.
3.	The conduction band is empty.	The conduction band contains electrons.
4.	The charge given to this is localized.	The charge given to this resides on the surface.
5.	The electrons take to and fro motion and do not leave the vicinity of the atom.	Here the electrons can take translatory motion and also leave the atom.
6.	Dielectrics do not conduct electricity.	Conductors conduct electricity.
7.	For a particular applied field strength, dielectric loses its insulation character, this minimum field strength is called break down strength.	There is no question of loosing conductivity character and break down strength does not arise.
8.	Examples :- Mica, Glass, Plastic etc.	Examples :- All metals.

Uses of dielectrics

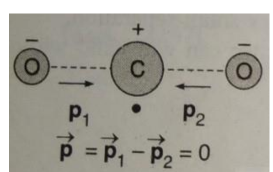
1. To increase the capacitance of the condensers dielectric materials like paper, Mica etc are placed in between the plates.
2. For insulation on electric conductors, dielectrics are used in form of layers around the conductors.
3. Dielectrics are also used for mechanical support to H.T. wires.
4. To increase the dielectric strength in electric fields dielectric materials are used.

Atomic view of dielectrics

The atoms or molecules consist of positive charges as well as negative charges in equal magnitude. The positive charges have one centre of gravity and negative charges have one centre of gravity.

Dielectrics are of two types. 1) Non-polar dielectrics 2) Polar dielectrics

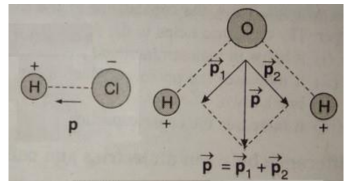
1) Non-polar dielectrics :- If the centre of gravity of positive charges coincides with the centre of gravity of negative charges, those molecules are called non-polar dielectrics. Ex:- H_2, N_2, O_2, CO_2 etc.



(a) Non-polar molecule

2) Polar dielectrics :- If the centre of gravity of positive charges does not coincide with the centre of gravity of negative charges, those molecules are called polar dielectrics.

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

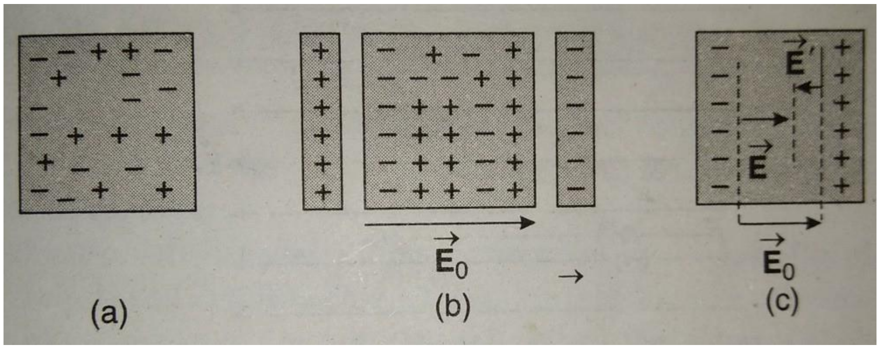


(b) Polar molecule

Behaviour of dielectrics in electric field

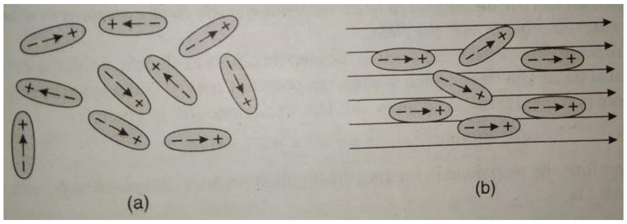
Non-polar dielectrics

- In general, non-polar dielectric molecules are randomly oriented such that the centres of gravity of positive and negative charges coincides with each other.
- When this material is placed between the electrodes of an electric field E_o, the molecules are reoriented such that the centres of gravity of positive charges are pulled towards the negative plate and vice versa. Then each molecule acts as a dipole.
- Separating the centres of gravity of positive and negative charges by applying electric field is called "polarization."
- If the applied field is increased then the separation also increases.
- Negative charges are induced on the surface of the dielectric which is towards the positive electrode and vice versa. These charges are called induced surface charges.
- The induced surface charges create induced electric field, "E^1" in opposite to the original electric field, E_o.
- The resultant electric field becomes $E = E_o - E^1$
- So, if the non-polar dielectric is placed in an electric field induced surface charges appear and the resultant electric field decreases.



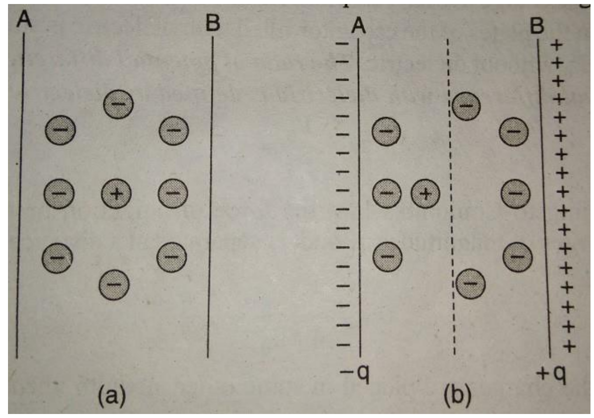
Polar dielectrics

- In absence of electric field also the centres of gravity of positive and negative are separated in polar dielectrics. So each molecule acts as a dipole.
- These dipoles are randomly oriented but having some dipole moment called permanent dipole moment "p_p."
- If this material is placed in an electric field, the positive centres of dipoles are pulled towards the negative electrode of the field and negative centres of dipoles are pulled towards the positive electrode of the field. So, the alignment changes with an increase of dipole moment. This increased dipole moment is called induced dipole moment "p_i."
- The resultant dipole moment becomes $p = p_p + p_i$
- So, if the polar dielectric is placed in an electric field induced dipole moment arises and the resultant dipole moment increases.



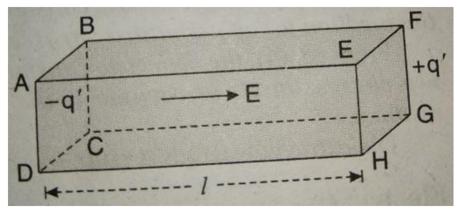
Dielectric polarization

- The atoms in dielectrics are symmetric when they are out side the electric field. Also the centres of gravity of positive and negative charges coincides each other.
- When the atoms are placed between plates of electric field, the electrons slightly displaced towards the positive plate and the nucleus slightly displaced towards the negative plate.



- The distorted atom is called <u>electric dipole</u> because the positive and negative charge centres are separated.
- Separating the centres of gravity of positive and negative charges by applying electric field is called "<u>dielectric polarization</u>."
- The dipole moment per unit volume is (the magnitude of) <u>dielectric polarization</u>.

Consider a dielectric slab having length l, and area of cross section A, placed in an electric field. Let the charges induced on the surfaces ABCD and EFGH of the dielectric are $-q^1$ and $+q^1$ respectively as shown in the figure.



$$Dielectric\ polarization\ (P) = \frac{Dipole\ moment}{Volume} = \frac{p}{V}$$

$$P = \frac{q^1 l}{Al} \qquad \because p = q^1 l \ \ and \qquad V = Al$$

$$\therefore \boxed{P = \frac{q^1}{A}}$$

Hence, *the dielectric polarization is equal to the induced surface charge density*.

<u>Dielectric constant</u> :-

<u>Definition(1)</u> :-It is defined as the ratio of the capacitance of a condenser with dielectric to the capacitance of the same condenser without dielectric.

$$\boxed{Dielectric\ constant\ (K) = \frac{\text{Capacitance of the condenser with dielectric}}{\text{Capacitance of the condenser without dielectric}} = \frac{C}{C_o}}$$

We know that

Capacitance of the condenser without dielectric $C_o = \frac{\epsilon_o A}{d}$

Capacitance of the condenser with dielectric $C = \frac{\epsilon A}{d}$

Here ϵ_o = Permittivity of the free space or air. ϵ = Permittivity of the dielectric medium.

A = Area of the condenser plate. d = Distance between the plates of the condenser.

$$\therefore \quad K = \frac{\frac{\epsilon A}{d}}{\frac{\epsilon_o A}{d}} \quad \text{i. e.} \quad \boxed{K = \frac{\epsilon}{\epsilon_o}} \quad \text{(or)} \quad \boxed{\epsilon = K\,\epsilon_o}$$

<u>Definition(2)</u> :- The dielectric constant of a dielectric medium is defined as the ratio of permittivity of the dielectric medium to the permittivity of the free space.

Also we know that the electrostatic forces between two charges in free space and in dielectric medium are given by $F_o = \frac{1}{4\pi g_o} \frac{q_1 q_2}{r^2}$ & $F = \frac{1}{4\pi g} \frac{q_1 q_2}{r^2}$

From these two eqns. $\frac{F_o}{F} = \frac{g}{g_o} = K$

<u>Definition(3)</u> :- The dielectric constant of a dielectric medium is defined as the ratio of the electrostatic force between two charges in free space to the electrostatic force between the same two charges in dielectric medium.

Similarly we can write $\frac{V_o}{V} = \frac{E_o}{E} = \frac{g}{g_o} = K$

<u>Definition(4)</u> :- The dielectric constant of a dielectric medium is defined as the ratio of the potential difference between two points in free space to the potential difference between the same two points in dielectric medium.

<u>Definition(5)</u> :- The dielectric constant of a dielectric medium is defined as the ratio of the electric field intensity at a point in free space to the electric field intensity at the same point in dielectric medium.

<u>Electric susceptibility</u> :-

When a dielectric material is placed in an electric field that material is polarized. If the electric field (E) is increased then the polarization (P) also increases.

$\therefore \quad P \propto E \quad (or) \quad P = 3E \quad (or) \quad 3 = \frac{P}{E}$

Here χ is a proportionality constant. It is called electric susceptibility.

<u>Definition</u> :- Electric susceptibility is the ratio of the electric polarization (P) created in the dielectric material to the electric field (E) applied.

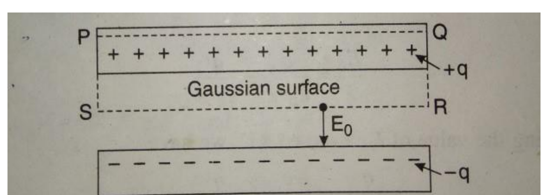
<u>Three electric vectors and their relation</u> (OR) <u>Relation among</u> $\overline{D}, \overline{E} \& \overline{P}$

<u>Electric field intensity (E)</u> :- The electric field intensity at a point in an electric field is equal to the electrostatic force acting on unit positive charge placed at that point.

<u>Dielectric polarization (P)</u> :- The dielectric polarization is the dipole moment per unit volume of the dielectric(or) It is the induced surface charge density ($P = q^1/A$).

<u>Electric displacement (D)</u> :- Electric displacement is an electric vector whose surface integral over a closed surface is equal to the free charge with in the closed surface (or) It is the free surface charge density ($D = q/A$)

Consider a parallel plate capacitor with out dielectric **(Figure.a).** Let the charges on the two plates are +q and -q. The electric field between the plates is E_o.



(a) Parallel plate condenser without dielectric. *PQRS* is the Gaussian surface enclosing charge +*q*.

Then as per the statement of Gauss law

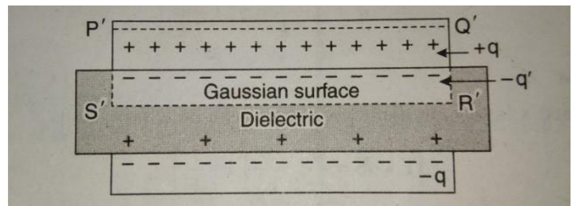
$$\oint \bar{E}_o \cdot d\bar{s} = \frac{q}{\epsilon_o}$$

Here q = charge with in the Gaussian surface PQRS.

$$E_o \oint dS. = \frac{q}{\epsilon_o} \quad \text{(or)} \quad E_o A = \frac{q}{\epsilon_o} \qquad \text{Here A = Area of the plate.}$$

$$\therefore \quad E_o = \frac{q}{\epsilon_o A} \longrightarrow (1)$$

- ✪ A dielectric slab of dielectric constant K is placed in between the plates of the condenser.
- ✪ Then polarization takes place in dielectric and induced surface charge $-q^1$ is moved towards the positive plate of the condenser **(Figure-b).**
- ✪ The net charge with in the Gaussian surface $P^1Q^1R^1S^1$ is $(q - q^1)$ and the electric field between the plates is E.



(b) Parallel plate condenser with dielectric, *P′ Q′ R′ S′* is the Gaussian surface enclosing charge $(q - q')$

From Gauss law (with dielectric) $\oint \bar{E}\, d\bar{s} = \frac{(q - q^1)}{\epsilon_o} \longrightarrow (2)$

(Or) $EA = \frac{(q - q^1)}{\epsilon_o}$

$$\therefore \; E = \frac{(q - q^1)}{\epsilon_o A} \quad \text{(or)} \quad E = \frac{q}{\epsilon_o A} - \frac{q^1}{\epsilon_o A} \longrightarrow (3)$$

$$E = \frac{1}{\epsilon_o}\left(\frac{q}{A} - \frac{q^1}{A}\right) \quad \text{(or)} \quad \epsilon_o E = \left(\frac{q}{A} - \frac{q^1}{A}\right) \longrightarrow (4)$$

We know that

$$\text{Induced surface charge density } \left(\frac{q^1}{A}\right) = \text{Dielectric polarization } (P)$$

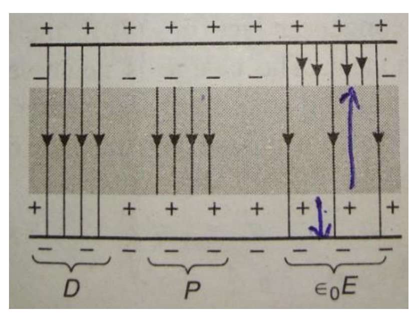
$$\text{Free surface charge density } \left(\frac{q}{A}\right) = \text{Electric displacement } (D)$$

Substituting these two values in eqn.(4)

$$\epsilon_o E = (D - P) \quad \text{(or)} \quad D = (\epsilon_o E + P)$$

D, E & P are vectors.

So, we can write this relation as $\boxed{\bar{D} = (\epsilon_o \bar{E} + \bar{P})}$



1) $\bar{D}$ is connected with the free charges only. It means its value can not change by the introduction of any dielectric.
2) $\bar{P}$ is connected with the induced charges in the dielectric only.
3) $\bar{E}$ is connected with free charges as well as induced charges.

<u>Relation between dielectric constant and electric susceptibility</u>

From the definitions

$$\text{Dielectric constant } (K) = \frac{\text{Permitivity of the dielectric medium } (\epsilon)}{\text{Permitivity of free space } (\epsilon_o)}$$

$$\boxed{K = \frac{g}{g_o}} \longrightarrow (1) \qquad \text{(or)} \qquad \epsilon = K\,\epsilon_o$$

& $$Electric\ susceptibility\ (3) = \frac{Electric\ polarization\ (P)}{Electric\ field\ intensity\ (E)}$$

$$3 = \frac{P}{E} \qquad \text{(or)} \qquad P = 3\,E$$

From the relation among D, E and P is $D = \epsilon_o E + P$

$$\epsilon\,E = \epsilon_o E + 3\,E \qquad \because\ D = \epsilon\,E\ \ and\ \ P = 3\,E$$

$$\epsilon = \epsilon_o + 3 \quad \text{(or)} \quad \boxed{3 = \epsilon - \epsilon_o} \longrightarrow (2)$$

$$3 = K\epsilon_o - \epsilon_o \quad \text{(or)} \quad \boxed{3 = (K-1)\epsilon_o}$$

This is the relation between dielectric constant and electric susceptibility.

From eqns. (1) & (2) it is known that

1. The ratio of the permittivity of the dielectric medium to the permittivity of free space is dielectric constant.
2. The difference between the permittivity of the dielectric medium & the permittivity of free space is electric susceptibility.

Method of Image

Introduction:

By this method, we avoid solving Poisson's or Laplace's equation but rather utilize the fact that a conducting surface is an equipotential.

Method of Image:

Typical examples of point, line, and volume charge configurations are portrayed in Figure 6.21(a), and their corresponding image configurations are in Figure 6.21(b).

Typical examples of point, line, and volume charge configurations are portrayed in Figure 6.21(a), and their corresponding image configurations are in Figure 6.21(b).

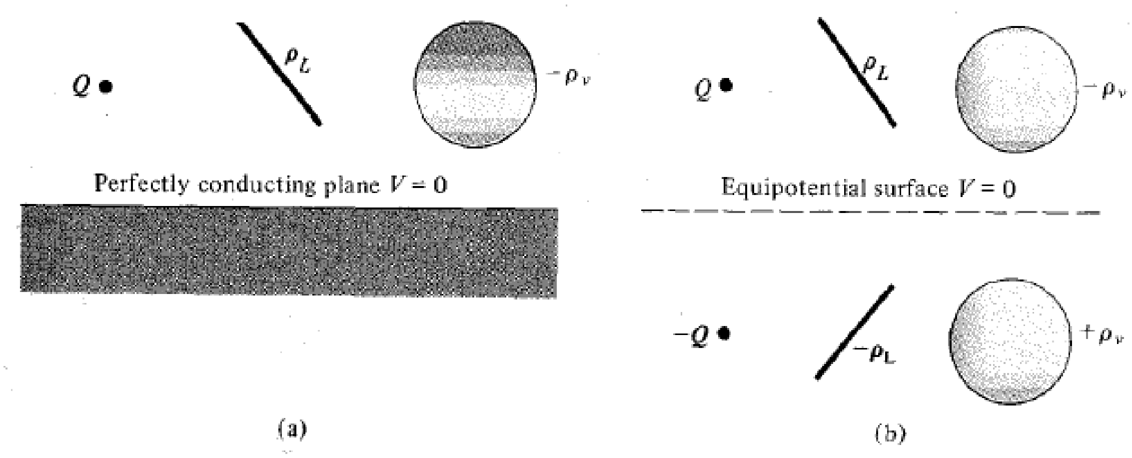


Figure 6.21 Image system: **(a)** charge configurations above a perfectly conducting plane; **(b)** image configuration with the conducting plane replaced by equipotential surface.

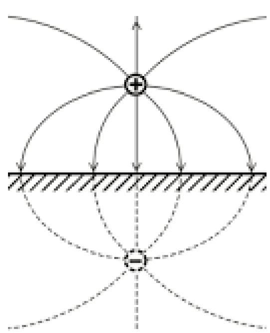
In applying the image method, two conditions must always be satisfied:

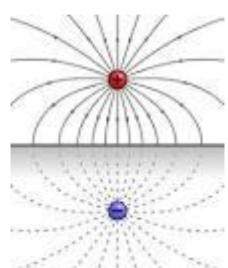
1. The image charge(s) must be located in the conducting region.
2. The image charge(s) must be located such that on the conducting surface(s) the potential is zero or constant.

The first condition is necessary to satisfy Poisson's equation, and the second condition ensures that the boundary conditions are satisfied

Method of images

Method of images (or method of mirror images) is used in electrostatics (magnetostatics) to simply calculate or visualize the distribution of the electric (magnetic) field of a charge (magnet) in a vicinity to the conducting (superconducting) surface.





This method of satisfying the boundary conditions imposed on the field of a point charge by a plane conductor by using an opposite charge at the mirror image position of the original charge, is called the method of images. The charge of opposite sign at the mirror-image position is the "image-charge."