[TH-4]

3rd SEM ELECTRICAL ENGG.

Under SCTE&VT, Odisha

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CHAPTER - II

INTRODUCTION

Insulators or dielectrics as distinct from conductors have no free electrons. Hence when a source of e.m.f is connected across a dielectric no current flows. However, since no dielectric is perfect it contains a small number of free electrons and a very small current flows through it when an electric field is applied. Capacitors therefore have a small leakage conductance.

EFFECT OF A DIELECTRIC ON THE BEHAVIOUR OF A CAPACITOR

Suppose that two large plane parallel plates separated by a distance d (meters) in vacuum are maintained at a potential difference V. The plates will become charged positively and negatively with charges = $Q_o$and a uniform electric field intensity E = V/d (volts/m) will be created between the plates. The magnitude of the charge accumulated on each plate is proportional to the applied potential difference, i.e$Q_o \propto V$ or $Q_o = C_oV$, where C_o is defined as the capacitance.

By applying Gauss theorem, the magnitude of flux density D within the plat given by

Since the electric field strength E is related to the flux density by the relation $D = \square_oE$, the field strength in the region between the plates is given by $E = D/\square_o = Q_o/A\square_o$. Since V = Ed, the capacitance of the system is given by $C_o = \square_oA/d$ where $\square_o$ is termed as the absolute permittivity of free space.

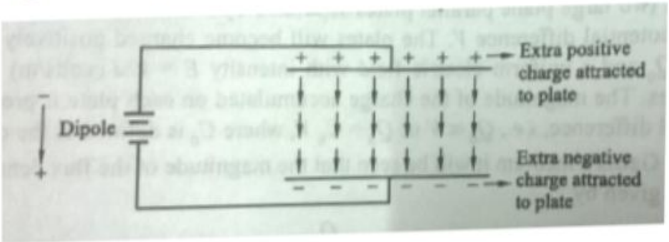
If the space between the plates is now filled with a dielectric and V is kept constant, it is found that the value of the charge is increased to Q = CV.

It follows that the new capacitance is given by $C = \square A/d$ where $\square$ is defined as the absolute permittivity of the dielectric and the ratio $\square_r = C/C_o = \square/\square_o$ is called the relative permittivity, specific inductive capacity or the dielectric constant of the material. The dielectric constant of a medium is constant if the state of the medium doesn't vary from point to point. At the boundary between two media the dielectric constant changes abruptly, and bodies that are non-homogeneous with respect to density and other properties are usually non-homogeneous with respect to the dielectric constant.

POLARISATION

A dielectric consists of molecules the atomic nuclei of which are effectively fixed, relative to each other. In absence of any external field the electrons are distributed symmetrically round the nucleus at any instant. When an electric field is applied the electrons of the atoms are acted upon by this field. This causes a movement of the electrons which are displaced in a direction opposite to that of the field. The resultant effect is to separate the positive and negative charges in each molecule so that they behave like electric dipoles. The strength of each dipole is given by the dipole moment which in its simplest form consists of two point charges of opposite sign $\pm Q$ separated by a distance d. The dipole moment has magnitude Qd and is represented by a vector pointing from the negative charge in the direction of the positive charge. The dipole moments are expressed in terms of the Debye unit.

When the dipoles are created the dielectric is said to be polarized or in state of polarization .When the field is removed and the atoms return to their normal or unpolarised state, the dipole disappear. The polarized dielectric consists of a layer of dipole as shown in fig below



There is an induced negative charge on the surface of the dielectric near the positive plate and a similar induced positive charge on the surface near negative plate. There is no resultant charge density at any point within the dielectric because all individual dipole are aligned parallel to the field, each negative charge of the one dipole being next to the positive charge of the next dipole.

Consider the dielectric to be composed of a large number of elementary cylinder each of length l in the direction of the applied field and of cross section δA. Let a uniform field of strength E be applied normal to the plates .This polarizes the dielectric inducing dipoles in each elementary cylinder and charges δq appear on either end of the cylinder. The charge density, σ on the surface δA of the cylinder given by

$$\sigma = \delta q/\delta A$$

$$= l.\delta q/l.\delta A$$

$$= m/\delta V$$

Where m is the dipole moment and δV is the volume of the elementary cylinder. If the number of dipoles per unit volume be N i.e., if N=I/Δv; then σ =Nm. The product Nm is called the polarization (P) of the dielectric and is the total dipole moment established within unit volume of the insulating medium. Thus a dielectric subjected to a homogenous field carries a dipole moment P per unit volume which may be written as P=Nm

The charge density σ is a scalar quantity but the polarization P is a vector quantity because it involves direction. For any dielectric, σ is equal to the normal component of the polarization. For an isotropic dielectric, the direction of polarization is perpendicular to the plates. Hence we may write $\sigma = P_n$, where P_n is the component of polarization perpendicular to the plates.

The electric polarization of a dielectric maybe conceived as a forced state of the medium caused by the action of an electromotive force and which disappear when that force is removed. In other words, it is a displacement of charge produced by an electromotive intensity. When emf acts on a conducting medium it produces a current through it, but if the medium is a non-conductor or dielectric, the current cannot continues so flow through the medium but electric charge would be displaced within the medium in the direction of the electromotive intensity.

If σ_0 represent the charge density on the plates of a condenser containing no dielectric and if σ_1 represent the charge density on the plates of the condenser filled with a homogenous dielectric then

$\sigma_0=Q_0/A=C_0\ V/d=\epsilon_0\ V/d=\epsilon_0 E_n$

Where E_n is the normal component of the electric field strength,

Similarly $\sigma_1=Q/A=C\ V/d=\epsilon\ V/d=\epsilon E_n$

i.e there is an increase in charge density. The increase may be observed experimentally. On removal of the dielectric, this additional charge return to the source. The additional attraction of charge to the condenser plates is explained by assuming that charges of opposite sign having a density $\epsilon_0 E_n(\epsilon_n-1)$ are formed on the surface of the dielectric next to the condenser plates,

Thus we may write,

$\sigma_1 > \sigma_0$

Where σ_{pol} is the charge density due to polarization or $\epsilon E_n=\epsilon_0 E_n + P_n$ Where $P_n=\epsilon_0 E\ (\epsilon_r-1)$.

The above expression may be written in the generalized from as,

$\epsilon E = \epsilon_0 E+P$

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

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

Or $P \propto E$, stating that the polarization P of a substance is proportional in magnitude to the applied field E, at all ordinary field strength, provided that the dielectric constant ϵ_r is independent of the applied field which it is for normal dielectrics below the breakdown field. The magnitude of polarization is expressed in coulombs/m^2.

Since polarization P is proportional to the dipole moment m, the latter must be proportional to the electric field strength or $m=\alpha E$. α is proportionality constant and is called the polarizability of the elementary dipole volume.

In deriving $P=\epsilon_0 E\ (\epsilon_r-1)$ the physical state of the dielectric was no considered.

Consider a gas containing N atoms/m^3 subjected to a homogenous field E, Neglecting any interaction between the dipoles induced in the atoms, which is an odd approximation for a gas , we find for the polarization of a gas ,

$$P=Nm=N\alpha E$$

Comparing this expression with the macroscopic expression for P, We have

$\epsilon_r=1+N\alpha/\epsilon_0$

When two plates in vacuum are charged initially to potential V, a uniform field is created between them and the intensity of the field is given by V/d. When a slab of permittivity ϵ is interposed between the plates, the capacity of the system is reduced by the factor ϵ.But since the potential difference between the plates is maintained by the battery, the charge on the plates should increase by a factor ϵ.Hence the charge per unit area is given by

$D_n=\epsilon\ E_0$

In accordance with the ideas of displacement a further quantity of charge in displaced per unit area between the plates. The additional charge displace per unit area at any point is represented by the normal component of the polarization vector P.

Hence,

$D_n = \varepsilon_0 E_n + P_n$

In general, the total displacement D at any point is now given by

$$D = D_0 + P$$

Or

$$D = \varepsilon_0 E + p$$

The above equation is valid for even anisotropic media where the polarization vector is not necessarily parallel to the electric field vector.

Since

$$P = N\alpha E$$

$$D = E\,(\varepsilon_0 + N_\alpha)$$

$$= [\varepsilon_0 + (\varepsilon_r - 1)\,\varepsilon_0]$$

$\varepsilon_r = 1 + (N/\varepsilon_0)$

$$D = \varepsilon_0 \varepsilon_r E$$

The above equation is valid only for isotropic material where the permittivity ε_r, remains constant in all directions. In crystals ε_r, generally depends on the direction along which it is measured relatively to the crystal axes. In polycrystalline materials, on the other hand, with a random distribution of gains, the directional effects disappear.

The essence of all electrostatic problems in the presence of dielectric materials is the determination of polarization P. All dielectric application depends upon the ability to vary P in some manner. P may be varied by changing the electric field, temperature, or mechanical strain. In most problems, it is required to find out the manner in which P varies with the electric field E. In an anisotropic material, the relationship between P and E may be very complex because the resultant polarization in a given direction may be a function of electric fields in all three mutually perpendicular directions. The simplest case is the three P is directly proportional to E i.e $P = K\varepsilon_0 E$. K is a dimensionless scalar quantity and is defined as the dielectric susceptance of the medium. Under these conditions, $\varepsilon_r = 1 + K$.

In case of isotropic materials, the relation between P and E may exhibit hysteresis in which case $D \neq \varepsilon_0 \varepsilon_r E$. Such materials are non-linear and are called ferroelectric materials. The figure below shows the polarization curve for such a material.