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Department of Physics

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RELATION BETWEEN THREE VECTORS D,E & P

D, E మరియు P సదిశల మధ్య సంబంధం

Three electric vectors are named as Electric Field Intensity(E), Dielectric Polarization(P) and Electric Displacement(D).

1. **Electric Field Intensity(E) (విద్యుత్ క్షేత్ర తీవ్రత)**

   The region surrounded by a charge in which another charge experiences a force is called as Electric field. The electric field intensity E at any point in the electric field is numerically equal to the force experienced by a unit positive charge placed at that point. The direction of E is the same as the direction of force

2. **Dielectric Polarization (P): (విద్యుత్ ధ్రువణం)**

   When a dielectric is placed in external electric field, induced surface charges appear. This process of separation of charges is known as dielectric polarization. When a dielectric is polarized, the distorted atom is called electric dipole. The dielectric polarization 'P' is defined as the ratio between dielectric dipole moment and Volume.

3. **Electric Displacement(D): (విద్యుత్ స్థానభ్రంశం)**

   When a dielectric slab is placed between the plates of a parallel plate capacitor, the medium is polarized due to which induced surface charges appear. The charge is negative near the positive plate of the condenser and positive near the negative plate of the condenser. The ratio charge per unit area is defined as Electric displacement vector.

Deduction of relation between the vectors

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Gauss law states that the total normal electric flux Φ_E over a closed is equal to $(1/\varepsilon_o)$ times the total charge Q enclosed within the surface

$\therefore \Phi_E = \oint E.dS = \frac{1}{\varepsilon_0}(q)$ where, E is Electric field vector and dS is surface area.

The aim of this topic is to derive a relation between the vectors E,P &D using a dielectric (with dielectric constant k) filled parallel plate capacitor. For this purpose, consider a parallel plate capacitor in two cases viz., with and without dielectric as shown in the following figure.

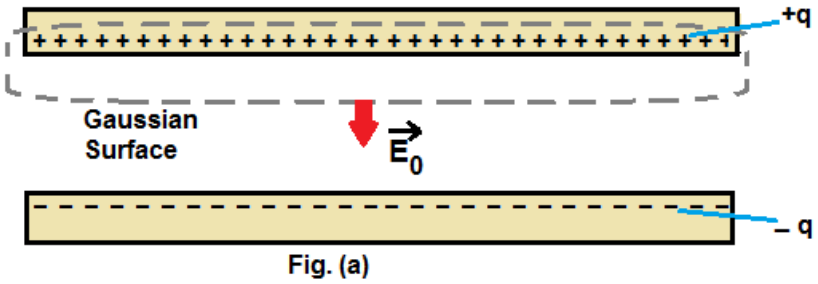

Fig. (a)

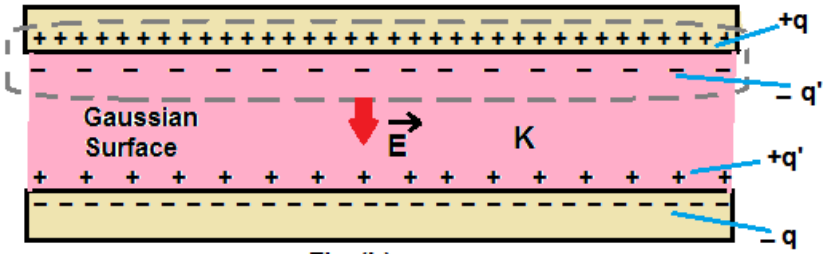

Fig. (b)

Here, the charge on either plates is 'q'. The electric field direction is as shown in the figure i.e., from positive plate to the negative plate. From Fig.(a), using Gauss law and its applicability, one can write,

$$\Phi_E = \oint E_0.dS = \frac{1}{\varepsilon_0}(q) \Longrightarrow E_0 \oint ds = E_0 A = \frac{q}{\varepsilon_0} \Longrightarrow E_0 = \frac{q}{\varepsilon_0 A} \qquad \text{------(1)}$$

Here, E_0 is the electric field when there is no dielectric and A is plate area

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When a dielectric is placed between the plates of the capacitor, induced surface charges appear as shown in Fig.(b). Let q′ be the induced surface charge on the dielectric. Due to the induced surface charge, the electric field will be changed. Let, E is the resultant electric field.

After construction of a Gaussian surface as shown in the figure and using Gauss law, one can write,

$$\oint E.dS = \frac{q-q'}{\varepsilon_0} \; or \; EA = \frac{q-q'}{\varepsilon} \Longrightarrow E = \frac{q-q'}{\varepsilon_0 A} \Longrightarrow E = \frac{q}{\varepsilon_0 A} - \frac{q'}{\varepsilon_0 A} \qquad \text{-----(2)}$$

Note: as induce charges produce their own electric field which opposes the external field, the resultant Electric field 'E' will be less that of E_0.

From the basic definition of dielectric constant $k=E_0/E$, one can write $E=E_0/k$. From equation (2),

$$\frac{E_0}{k} = \frac{q}{\varepsilon_0 A} - \frac{q'}{\varepsilon_0 A} \Longrightarrow \frac{q}{k\varepsilon_0 A} = \frac{q}{\varepsilon_0 A} - \frac{q'}{\varepsilon_0 A}$$

$$\frac{q}{A} = \varepsilon_0 \left[\frac{q}{k\varepsilon_0 A}\right] - \frac{q'}{A}$$

Substituting the value of E_0 from equation (1),

$$As \; \frac{q}{k\varepsilon_0 A} = E \; and \; \frac{q'}{A} = P, we \; put \; the \; ratio \; \frac{q}{A} = D \; and \; is \; termed \; as \; Electric \; Dsiplacement.$$

Therefore, $D=\varepsilon_0 E+P$ -------(3)

In presence of dielectric, Gauss law can be written in terms of polarization as,

$$\oint E.dS = \frac{q-q'}{\epsilon_0} \Longrightarrow \epsilon_0 \oint E.dS = q - q' = q - \oint P.dS$$

$$\Longrightarrow \oint(\varepsilon_0 E + P).dS = q \; \Longrightarrow \oint D.dS = q$$

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Therefore, the electric displacement vector D is defined as a vector quantity whose surface integral over any charged surface (Flux of D) is equal to the free charge within the surface.

Important points:

1. The vector D is connected with free charge only and will not be affected by the introduction of dielectric.
2. The vector 'P' is connected with polarization charge only. the lines of 'P' begin and end on polarization charges
3. The vector 'E' is connected with all the charges present at that instant of time.

D and P in terms of 'E'

As it is already established, the vectors D and P are separately connection to E.

It is known that $E = \frac{q}{k\varepsilon_0 A}$ or $\frac{q}{A} = \varepsilon_0 kE$, $\therefore D = \varepsilon_0 kE$

From the definition of k, $k\varepsilon_0=\varepsilon$

Therefore the equation changes as $D=\varepsilon E$.

By substitution of the value of D in equation (9), we get

$\epsilon_0 kE = \varepsilon_0 \mathrm{E} + \mathrm{P} \implies \mathrm{P} = \varepsilon_0(\mathrm{k}-1)\mathrm{E}$

The value of $\varepsilon_0(k-1)$ is called as electric susceptibility 'χ' of the dielectric. Therefore, $P= \chi E$. The three quantities ε_0, k and χ describe the properties of dielectric. These are related by the relation

$$\chi = \varepsilon_0(\mathrm{k}-1) = \varepsilon_0 \mathrm{k} - \varepsilon_0 \implies \varepsilon = \varepsilon_0 + \chi$$

Dividing this expression with ε_0, we get

$$\frac{\varepsilon}{\varepsilon_0} = \frac{\varepsilon_0 + \chi}{\varepsilon_0} = 1 + \frac{\chi}{\varepsilon_0} \implies k = 1 + \frac{\chi}{\varepsilon_0}$$

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Questions

1. Define the vectors D, E and P. deduce the relation between them
2. What is electric displacement? Explain how the electric displacement and Electric intensity are related.
3. Define electric displacement vector, polarization and intensity of electric field.
4. Define electric susceptibility. Show that $k = 1 + \frac{\chi}{\varepsilon_0}$.
5. Define dielectric constant and electric susceptibility. Derive a relation between them.
6. Deduce Gauss law for dielectrics. Derive a relation between the vectors D, E and P.

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