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Department of Physics

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GAUSS LAW IN DIELECTRICS

Gauss Law:

Gauss law states that the total normal electric flux Φ_E over a closed is equal to $(1/\varepsilon_0)$ 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 an expression for Gauss law using a dielectric (with dielectric constant k) filled parallel plate capacitor. Consider, a parallel plate capacitor in two cases viz., with and without dielectric as shown in the following figure.

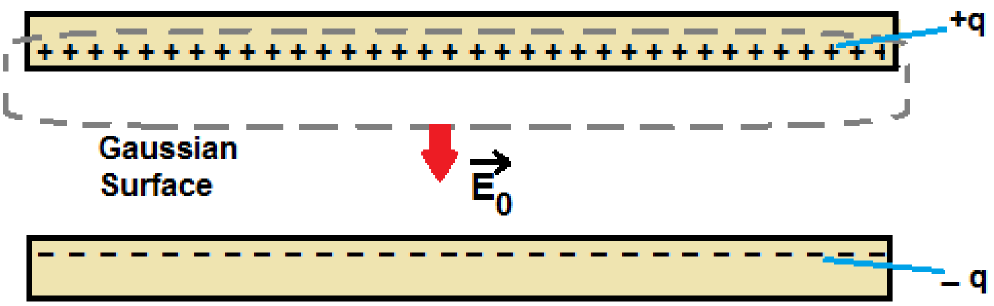

Fig. (a)

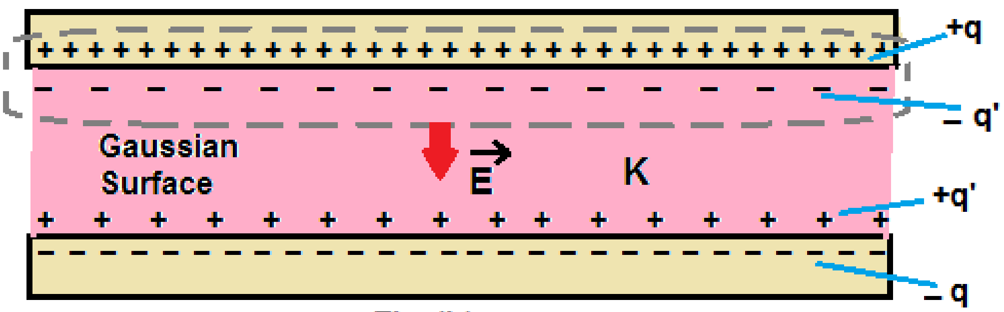

Fig. (b)

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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

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,

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

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),

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

Substituting the value of E_0 from equation (1),

$$\frac{q}{k\varepsilon_0 A} = \frac{q}{\varepsilon_0 A} - \frac{q'}{\varepsilon_0 A} \Longrightarrow q' = q - \frac{q}{k} = q' = q\left[1 - \frac{1}{k}\right] \qquad \text{------(3)}$$

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In presence of dielectric, Gauss law can be written as,

$$\oint E.dS = \frac{q}{\varepsilon_0} - \frac{q'}{\varepsilon_0} = \frac{q}{\varepsilon_0} - \frac{q}{\varepsilon_0}\left[1 - \frac{1}{k}\right] \Longrightarrow \oint E.dS = \frac{q}{\varepsilon_0} - \frac{q}{\varepsilon_0} + \frac{q}{\varepsilon_0 k}$$

$k \oint E.dS = \frac{q}{\varepsilon_0}$. This equation gives an expression for Gauss law in dielectrics

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