It is very important to note that the electrification of the body (whether positive or negative) is due to transfer of electrons from one body to another.

i.e. If the electrons are transferred from a body, then the deficiency of electrons makes the body positive.

If the electrons are gained by a body, then the excess of electrons makes the body negative.

If the two bodies from the following list are rubbed, then the body appearing early in the list is positively charges whereas the latter is negatively charged.

Fur, Glass, Silk, Human body, Cotton, Wood, Sealing wax, Amber, Resin, Sulphur, Rubber, Ebonite.

Column I (+ve Charge)	Column II (-ve Charge)
Glass	Silk
Wool, Flannel	Amber, Ebonite, Rubber, Plastic
Ebonite	Polythene
Dry hair	Comb

$$\vec{E}_Q = \frac{1}{4\pi\varepsilon_0} \frac{p}{(x^2 + l^2)^{3/2}} (-\hat{i})$$

If l << y, then

$$\boxed{E_Q \approx \frac{p}{4\pi\varepsilon_0 \; y^3}}$$

The direction of electric field intensity at a point on the equatorial line due to a dipole is parallel and opposite to the direction of the dipole moment.

If the observation point is far away or when the dipole is very short, then the electric field intensity at a point on the axial line is double the electric field intensity at a point on the equatorial line.

i.e. If l << x and l << y, then $E_P = 2\,E_Q$

$$W_{AB} = \int dW = -\int_A^B \vec{E} \cdot \vec{dl} = \frac{qq_0}{4\pi\varepsilon_0}\left[\frac{1}{r_B} - \frac{1}{r_A}\right]$$

1. The equation shows that the work done in moving a test charge q_0 from point A to another point B along any path AB in an electric field due to +q charge depends only on the positions of these points and is independent of the actual path followed between A and B.

2. That is, the line integral of electric field is path independent.

3. Therefore, electric field is 'conservative field'.

4. Line integral of electric field over a closed path is zero. This is another condition satisfied by conservative field.

$$\oint_A^B \vec{E} \cdot \vec{dl} = 0$$

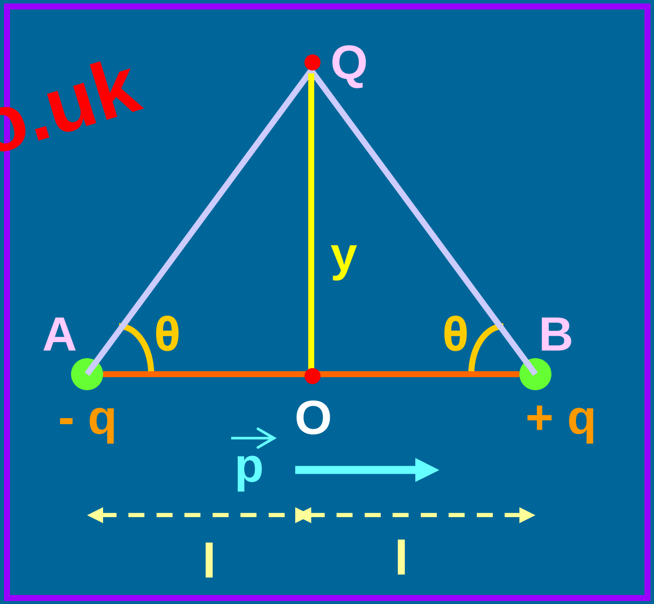
Note:

Line integral of only static electric field is independent of the path followed. However, line integral of the field due to a moving charge is not independent of the path because the field varies with time.

ii) At a point on the equatorial line:

$$V_{Q_{q+}} = \frac{1}{4\pi\varepsilon_0} \frac{q}{BQ}$$

$$V_{Q_{q-}} = \frac{1}{4\pi\varepsilon_0} \frac{-q}{AQ}$$



$$V_Q = V_{P_{q+}} + V_{P_{q-}}$$

$$V_Q = \frac{q}{4\pi\varepsilon_0} \left[\frac{1}{BQ} - \frac{1}{AQ} \right]$$

$\boxed{V_Q = 0}$ $\because$ $BQ = AQ$

The net electrostatic potential at a point in the electric field due to an electric dipole at any point on the equatorial line is zero.

3. Equipotential surfaces indicate regions of strong or weak electric fields.

Electric field is defined as the negative potential gradient.

$$\therefore \quad E = -\frac{dV}{dr} \quad \text{or} \quad dr = -\frac{dV}{E}$$

Since dV is constant on equipotential surface, so

$$dr \propto \frac{1}{E}$$

If E is strong (large), dr will be small, i.e. the separation of equipotential surfaces will be smaller (i.e. equipotential surfaces are crowded) and vice versa.

4. Two equipotential surfaces can not intersect.

If two equipotential surfaces intersect, then at the points of intersection, there will be two values of the electric potential which is not possible.

(Refer to properties of electric lines of force)

Note:

Electric potential is a scalar quantity whereas potential gradient is a vector quantity.

The negative sign of potential gradient shows that the rate of change of potential with distance is always against the electric field intensity.

Proof of Gauss's Theorem for a Closed Surface of any Shape:

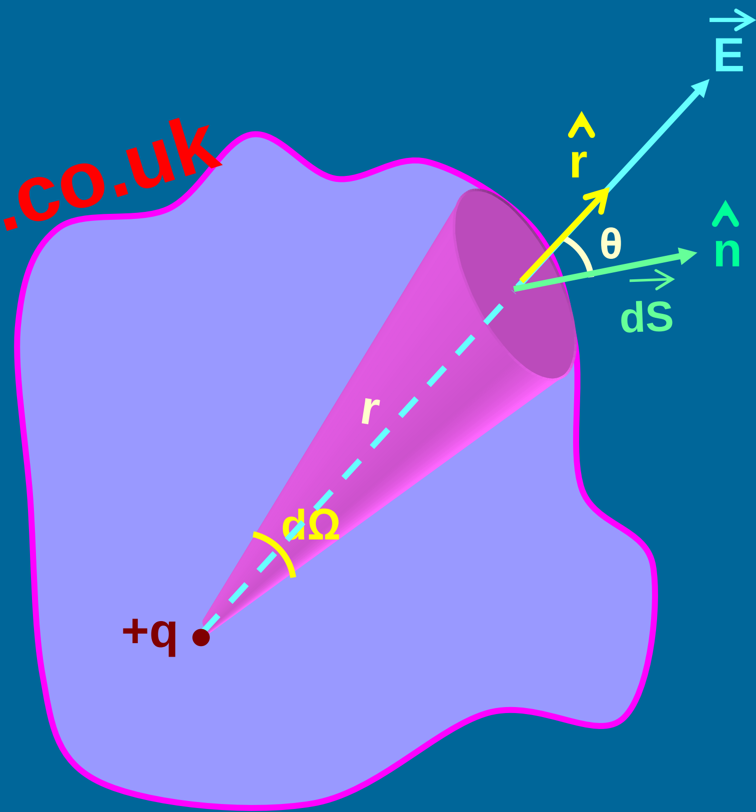
$$d\Phi = \vec{E} \cdot \vec{dS} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\,\hat{r} \cdot dS\,\hat{n}$$

$$d\Phi = \frac{1}{4\pi\varepsilon_0}\frac{q\,dS}{r^2}\,\hat{r} \cdot \hat{n}$$

Here, $\hat{r} \cdot \hat{n} = 1 \times 1 \cos\theta$

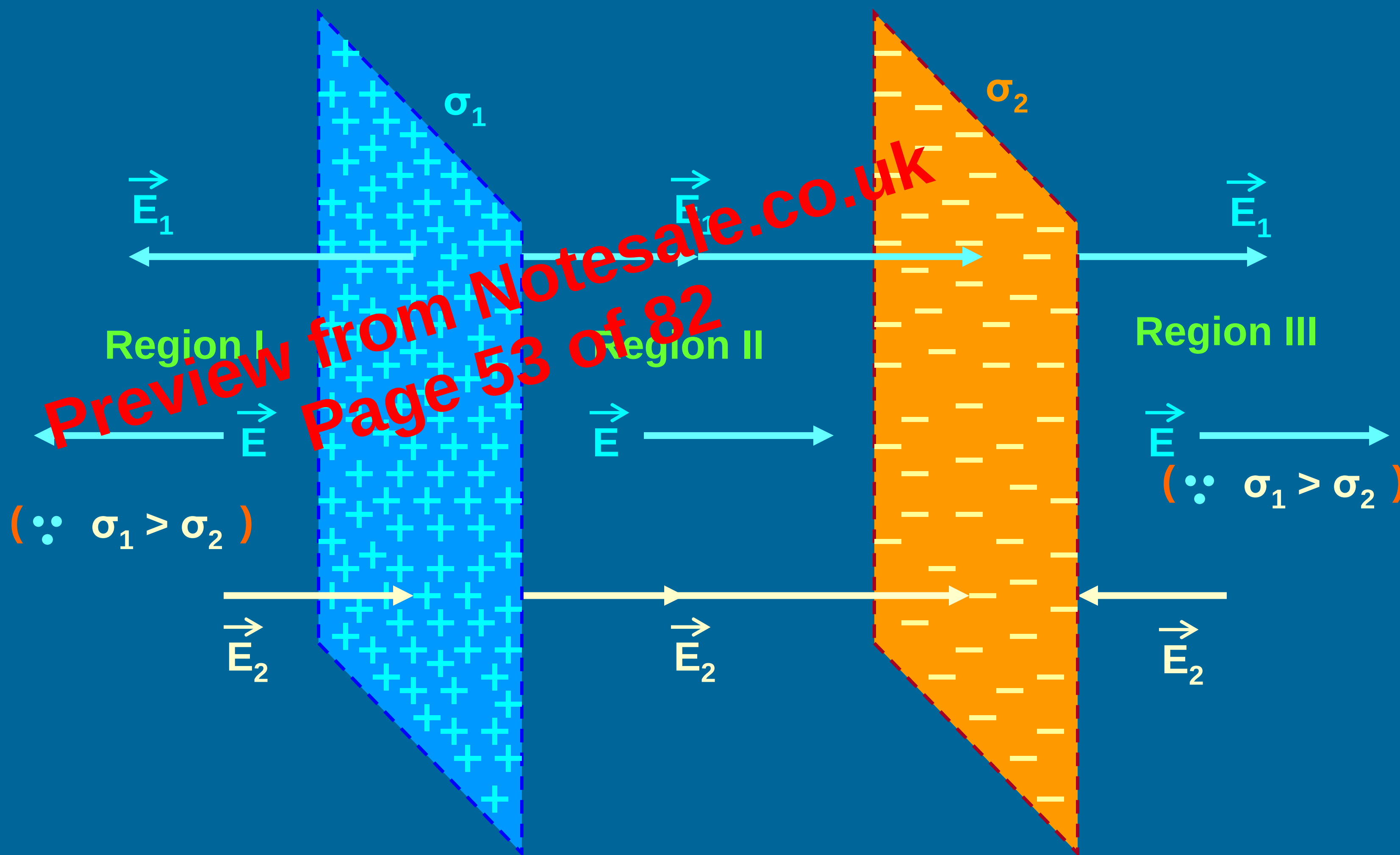
$= \cos\theta$

$$\therefore \quad d\Phi = \frac{q}{4\pi\varepsilon_0}\frac{dS\cos\theta}{r^2}$$



$$\Phi_E = \oint_S d\Phi = \frac{q}{4\pi\varepsilon_0}\oint_S d\Omega = \frac{q}{4\pi\varepsilon_0}4\pi = \frac{q}{\varepsilon_0}$$

Case 2: $+\sigma_1$ & $-\sigma_2$



$E = E_1 - E_2$ $E = \dfrac{\sigma_1 - \sigma_2}{2\,\varepsilon_0}$	$E = E_1 + E_2$ $E = \dfrac{\sigma_1 + \sigma_2}{2\,\varepsilon_0}$	$E = E_1 - E_2$ $E = \dfrac{\sigma_1 - \sigma_2}{2\,\varepsilon_0}$

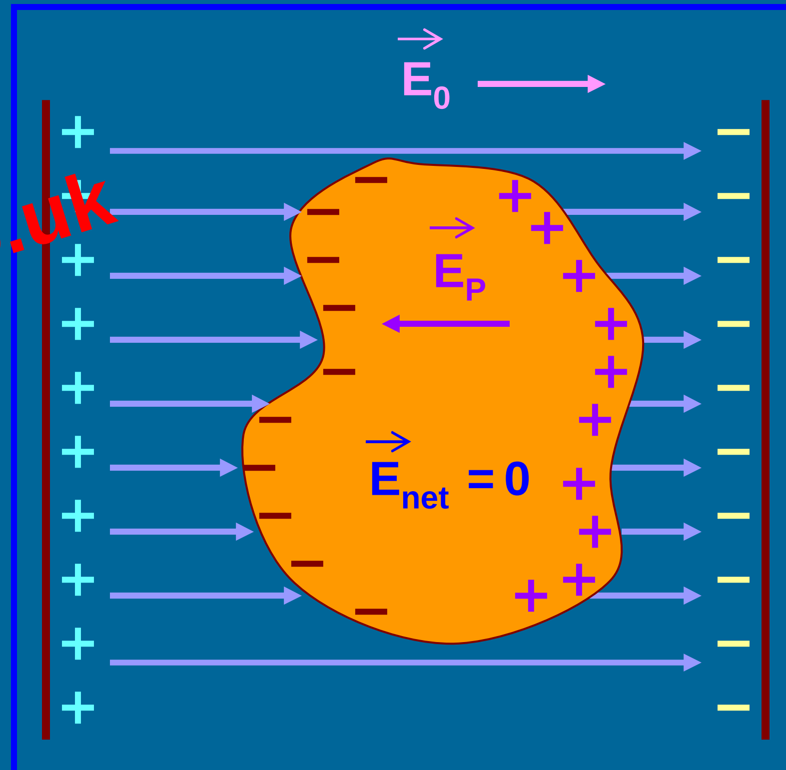
ELECTROSTATICS - IV

- Capacitance and Van de Graaff Generator

Behaviour of Conductors in the Electrostatic Field:

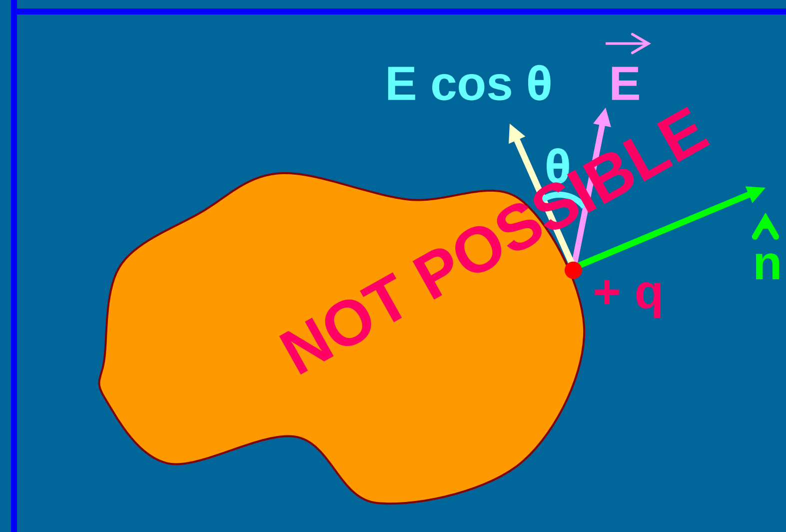
1. **Net electric field intensity in the interior of a conductor is zero.**

   When a conductor is placed in an electrostatic field, the charges (free electrons) drift towards the positive plate leaving the + ve core behind. At an equilibrium, the electric field due to the polarisation becomes equal to the applied field. So, the net electrostatic field inside the conductor is zero.



2. **Electric field just outside the charged conductor is perpendicular to the surface of the conductor.**

   Suppose the electric field is acting at an angle other than 90°, then there will be a component E cos θ acting along the tangent at that point to the surface which will tend to accelerate the charge on the surface leading to 'surface current'. But there is no surface current in electrostatics. So, θ = 90° and cos 90° = 0.

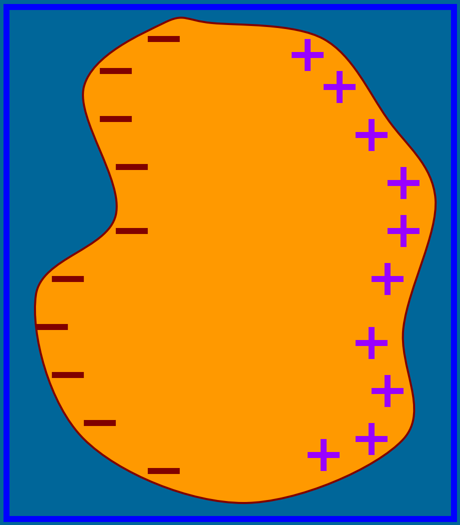


3. Net charge in the interior of a conductor is zero.

The charges are temporarily separated. The total charge of the system is zero.

$$\Phi_E = \oint_S \vec{E} \cdot d\vec{S} = \frac{q}{\varepsilon_0}$$

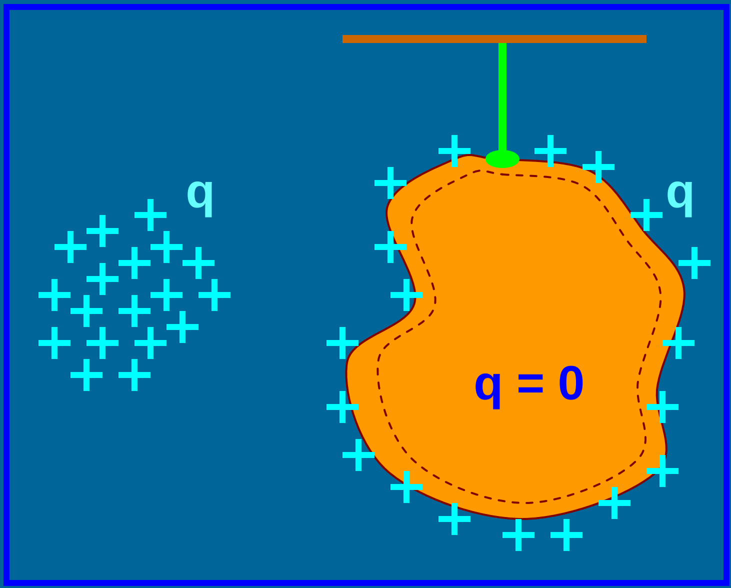
Since E = 0 in the interior of the conductor, therefore q = 0.



4. Charge always resides on the surface of a conductor.

Suppose a conductor is given some excess charge q. Construct a Gaussian surface just inside the conductor.

Since E = 0 in the interior of the conductor, therefore q = 0 inside the conductor.



5. Electric potential is constant for the entire conductor.

dV = - E . dr

Since E = 0 in the interior of the conductor, therefore dV = 0. i.e. V = constant

Dielectrics:

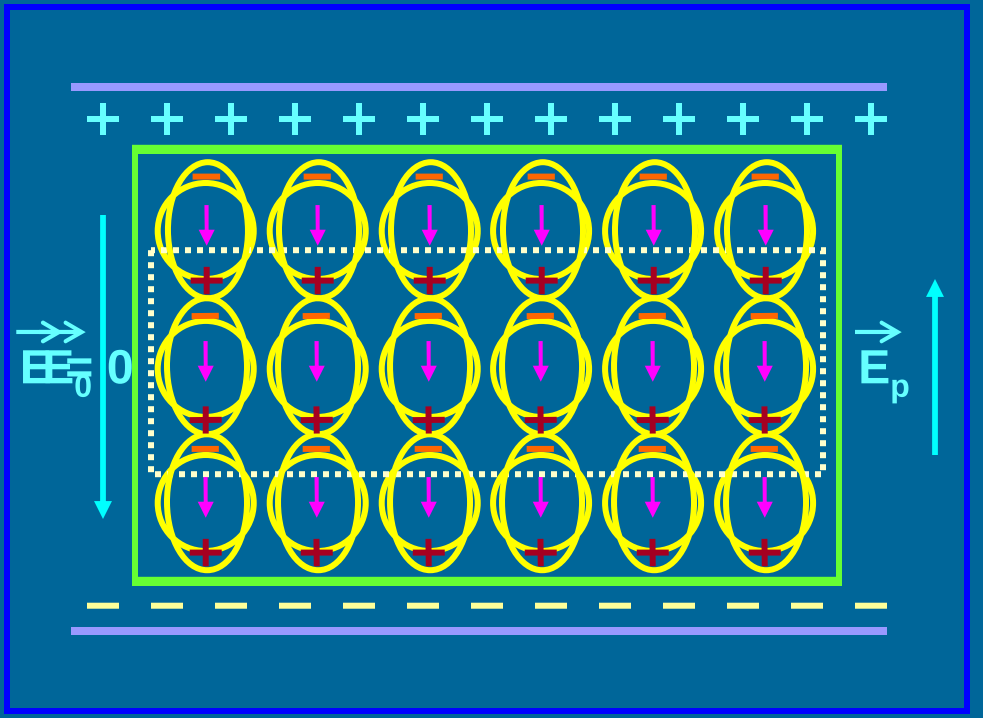
Generally, a non-conducting medium or insulator is called a ‘dielectric’.

Precisely, the non-conducting materials in which induced charges are produced on their faces on the application of electric fields are called dielectrics.

Eg. Air, H_2, glass, mica, paraffin wax, transformer oil, etc.

Polarization of Dielectrics:

When a non-polar dielectric slab is subjected to an electric field, dipoles are induced due to separation of effective positive and negative centres.



E_0 is the applied field and E_p is the induced field in the dielectric.

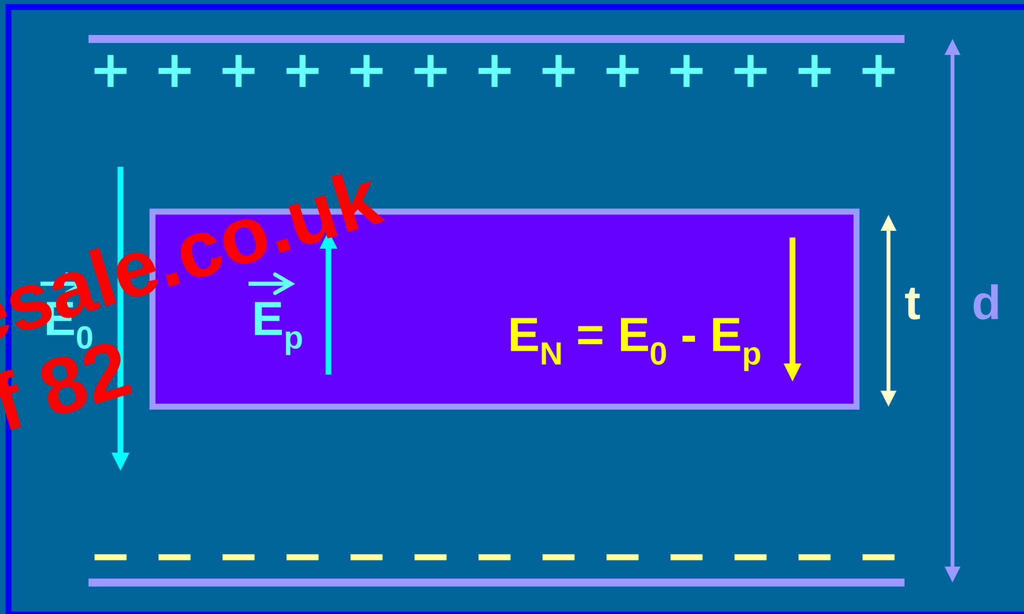
The net field is $E_N = E_0 - E_p$

i.e. the field is reduced when a dielectric slab is introduced.

The dielectric constant is given by

$$K = \frac{E_0}{E_0 - E_p}$$

Capacitance of Parallel Plate Capacitor with Dielectric Slab:



$$V = E_0\,(d - t) + E_N\,t$$

$$K = \frac{E_0}{E_N} \quad \text{or} \quad E_N = \frac{E_0}{K}$$

$$\therefore \quad V = E_0\,(d - t) + \frac{E_0}{K}\,t$$

$$V = E_0 \left[(d - t) + \frac{t}{K} \right]$$

But $$E_0 = \frac{\sigma}{\varepsilon_0} = \frac{qA}{\varepsilon_0}$$

and $$C = \frac{q}{V}$$

$$\therefore \quad C = \frac{A\,\varepsilon_0}{\left[(d - t) + \frac{t}{K} \right]}$$

or $$C = \frac{A\,\varepsilon_0}{d\left[1 - \frac{t}{d}\left(1 - \frac{t}{K}\right)\right]}$$

or $$\boxed{C = \frac{C_0}{\left[1 - \frac{t}{d}\left(1 - \frac{t}{K}\right)\right]}}$$

$C > C_0$. i.e. Capacitance increases with introduction of dielectric slab.

Uses:

Van de Graaff Generator is used to produce very high potential difference (of the order of several million volts) for accelerating charged particles.

The beam of accelerated charged particles are used to trigger nuclear reactions.

The beam is used to break atoms for various experiments in Physics.

In medicine, such beams are used to treat cancer.

It is used for research purposes.