Class notes on Electrostatics-2

Semester- 2

Sub- Applied Physics-II

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* Properties of Electric Lines of Force:

1) The lines of force are continuous lines or curves without any break.

2) The lines of force start at positive charges and end at negative charges.

3) No two lines of force can cross each other.

* Electric Potential: The electric potential at any point in an electric field is defined as the amount of work done in bringing a unit positive charge from infinity to that point against the electrostatic force.

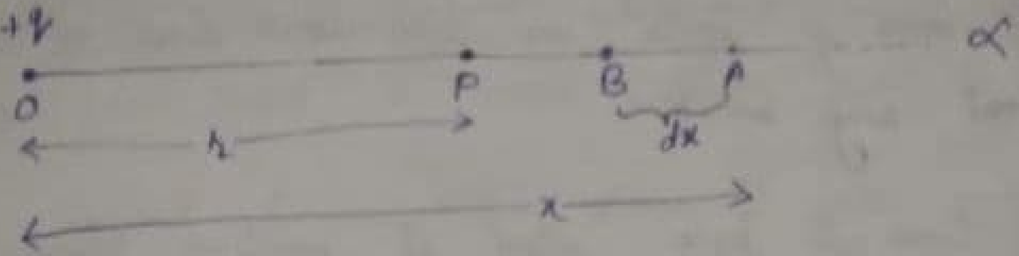
If 'W' is the work done in bringing the test charge q_0 then potential is given by—

$$\boxed{V = \frac{W}{q_0}}$$

* The potential of the earth cannot be changed by addition or subtraction of charges.

* Potential Difference: The potential difference between two points is the amount of work done in moving a unit positive charge from one point to the other point.

* Potential at a point due to a point charge:



Let us consider a point charge $+q$ at 'O'. We have to calculate the potential due to $+q$ at point P.

If we place a test at 'A' at a distance x from O. The force -

$$F = \frac{1}{4\pi\epsilon_0}\frac{q q_0}{x^2}$$

The small amount of work done in moving the test charge from A to B by a small distance dx -

$$dW = \vec{F}.\vec{dx}$$
$$= F\,dx\cos\theta$$
$$= F\,dx\cos 180^\circ$$
$$= -F\,dx$$

So, the total work done in moving the charge q_0 from infinity to the point 'P' will be -

$$W = \int dW = -\int_{\infty}^{r} F\,dx$$

$$W = -\int_{\alpha}^{r} \frac{1}{4\pi\epsilon_0} \frac{q q_0}{x^2} dx$$

$$= -\frac{q q_0}{4\pi\epsilon_0} \int_{\alpha}^{r} x^{-2} dx$$

$$= -\frac{q q_0}{4\pi\epsilon_0} \left[-\frac{1}{x}\right]_{\alpha}^{r}$$

$$= \frac{q q_0}{4\pi\epsilon_0} \left[\frac{1}{r} - \frac{1}{\alpha}\right]$$

$$= \frac{1}{4\pi\epsilon_0} \cdot \frac{q q_0}{r}$$

Hence, by definition of potential –

$$V = \frac{W}{q_0}$$

$$\Rightarrow \boxed{V = \frac{1}{4\pi\epsilon_0} \cdot \frac{q}{r}}$$

* <u>Capacitance</u>: The capacitance of a conductor may be defined as the ratio between the charge on the conductor to its potential.

$$\boxed{C = \frac{Q}{V}}$$

The SI unit of capacitance is farad (F)

$$1\ \text{Farad} = \frac{1\ \text{coulomb}}{1\ \text{Volt}}$$

* Parallel Plate capacitor :

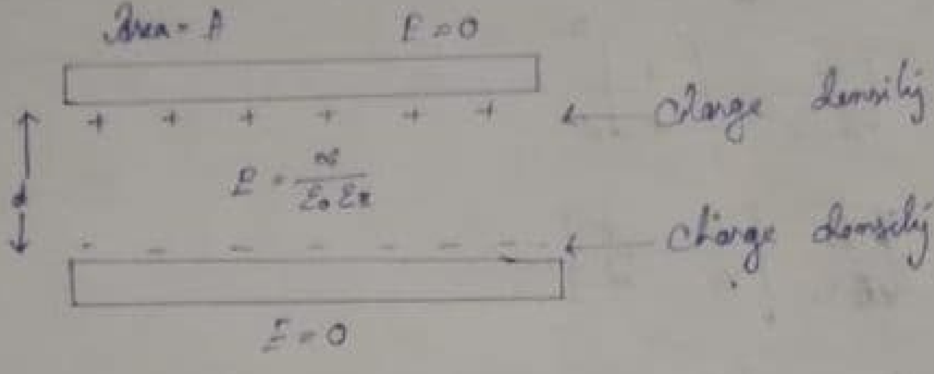


Fig: Parallel Plate Capacitor

A parallel plate capacitor consists of two large plane parallel conducting plates separated by a small distance.

If ε_0 and ε_r are the permittivity of free space and relative permittivity of enclosing medium, then as shown in the fig the electric field in between the plates is given by–

$$E = \frac{\sigma}{\varepsilon_0 \varepsilon_r} \quad \text{--- (i)}$$

The potential i.e work done in taking a test charge from lower plate to upper plate is –

$$V = \text{Force per unit charge} \times \text{distance}$$

$$V = \frac{\sigma d}{\varepsilon_0 \varepsilon_r} \quad \text{--- (ii)}$$

But we know,

$$C = \frac{Q}{V}$$

$$C = \frac{\varepsilon A}{\varepsilon d} \times \varepsilon_0 \varepsilon_r$$

$$\Rightarrow \boxed{C = \frac{\varepsilon_0 \varepsilon_r . A}{d}} \quad — (3)$$

From the eqⁿ (3) we can conclude the following :-

(i) Capacitance depends on area of the plate.

(ii) Capacitance depends on permitivity of the medium between the two plates

(iii) Capacitance is inversely proportional to the distance between the plates.

* <u>Energy stored in capacitor</u> :

* Potential energy of a capacitor is defined as the amount of work done to charge the capacitor.

Let q and V be the instantaneous charge and potential respectively of a capacitor (c) during the process of charging

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

Now, if an additional charge dq moved from infinity to capacitor, work done is -

$$dW = V \cdot dq$$

$$\Rightarrow dW = \frac{q}{C} \cdot dq$$

The total work done in bringing total charge Q to the capacitor –

$$W = \int_0^W dW = \int_0^Q \frac{q}{C} \cdot dq$$

$$W = \frac{1}{C} \left[\frac{q^2}{2} \right]_0^Q$$

$$= \frac{1}{C} \left[\frac{Q^2}{2} - \frac{0^2}{2} \right]$$

$$= \frac{1}{C} \cdot \frac{Q^2}{2}$$

$$= \frac{1}{C} \frac{(CV)^2}{2}$$

$$W = \frac{1}{2} CV^2$$

This is the potential energy stored in a capacitor.