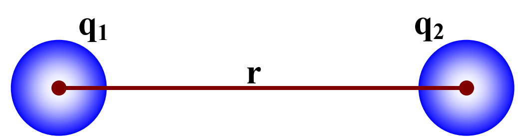
2. STATIC ELECTRICITY

Electric Charge

- When a glass rod is rubbed with silk, glass rod acquiring the property of attracting light objects like feather of birds, small bit of paper etc. Similarly an ebonite rod acquiring the attractive property on being rubbed with flannel, and if we comb dry hair with a rubber comb, the comb acquires the property of attracting small bit of paper etc.
- The electricity developed on bodies, when they are rubbed with each other is called **frictional electricity**. It is also called **static electricity**, as the charges so developed cannot flow from one point to some other point.
- There are two types of charges. (1) Positive charge and (2) Negative charge. The like charges repel each other and unlike charges attract each other.
- The modern concept of electrification is based on the fact that under normal conditions matter contains equal number of positive and negative charge. When two bodies are rubbed together some amount of charge is transferred from one body to another and this results in changing the electrical neutrality of both bodies. This is because a charge transfer takes place. The body, which loses electrons, becomes positively charged while the body, which receives electrons, becomes negatively charged.

Coulomb's Law

- According Coulomb's Inverse Square law, the force of attraction or repulsion between two point charges is directly proportional to the product of magnitude of charges and inversely proportional to the square of the distance between them.
- Let $\mathbf{q_1}$ and $\mathbf{q_2}$ are the two stationary charges separated by distance **'r',** and then the electrostatic force between them is given by



$$\therefore \mathbf{F} \propto \frac{\mathbf{q_1\, q_2}}{\mathbf{r^2}}$$

$$\therefore \mathbf{F} = \mathbf{k}\frac{\mathbf{q_1\, q_2}}{\mathbf{r^2}}$$

$$\therefore \mathbf{F} = \frac{\mathbf{1}}{\mathbf{4\pi\, \varepsilon_0\, \varepsilon_r}}\frac{\mathbf{q_1\, q_2}}{\mathbf{r^2}}$$

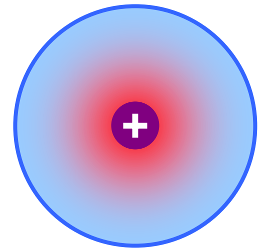
- Where $\mathbf{K(air)} = \frac{1}{4\pi\, \varepsilon_0 \varepsilon_r}$ = **9 × 10⁹ N-m²/C²** is the constant of proportionality. It value depends on the nature of the medium in which two charges are located and the system of units adopted to measure.
- In above equation, $\boldsymbol{\varepsilon = \varepsilon_0\, \varepsilon_r}$ is known as permittivity constant.

  $\boldsymbol{\varepsilon_0}$ = Absolute permittivity of air or vacuum = $\mathbf{8.854 \times 10^{-12}\ C^2/N\text{-}m^2}$

  $\boldsymbol{\varepsilon_r}$ = Dielectric constant or relative permittivity of the medium.

  $\boldsymbol{\varepsilon_r = 1}$ for air or vacuum.
- If we take $q_1 = q_2 = 1$coulomb, $\boldsymbol{\varepsilon_r = 1}$ for air and r = 1meter, Then $F = K = 9 \times 10^9$ N.
- Thus one coulomb is that quantity of charge which will repel an equal and similar charge with a force of 9×10^9 N, when placed in vacuum (or air) at a distance of one meter from it.

Electric Field



- An electric field is defined as the space surrounding an electric charge where its effect such as attraction or repulsion is experienced by other charge.

Intensity of Electric Field(E)

- The **strength** or **intensity** of electric field at any point is defined as the force experienced by a unit positive charge, placed at that point
- Let **F** be the force experience by a charge $\mathbf{q_1}$ coulomb placed at given point in electric field of charge **q**, than the intensity due to a charge **q** at a distance '**r**' is given by

$$\mathbf{E} = \frac{\mathbf{F}}{\mathbf{q_1}} \qquad \text{------------------------(1)}$$

- Now from Coulomb's law, the force between charge **q** and $\mathbf{q_1}$ at a distance **r** is given by

$$\mathbf{F} = \frac{\mathbf{q_1 q}}{\mathbf{4\pi\, \varepsilon_0 \varepsilon_r\, r^2}} \qquad \text{-----------------(2)}$$

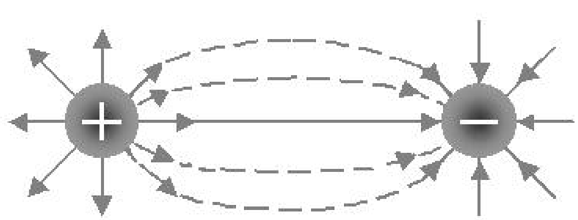
From equation (1) and (2), we get

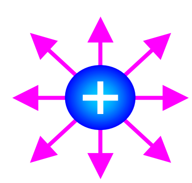
$$\mathbf{E} = \frac{\mathbf{q}}{\mathbf{4\pi\, \varepsilon_0 \varepsilon_r r^2}}$$

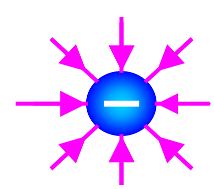
- The electric intensity (**E**) is a vector quantity that has magnitude and direction. The direction of **E** is along the direction of the force.
- The unit of intensity of electric field is **Newton/coulomb** or **coulomb/m^2.**

Electric Lines of Force

- Electric field is represented with the help of electric lines of force. Electric line of force is defined as the path along which a unit positive would tend to move when free to do so in an in an electric field.







Properties of electric lines of force:

1. The electric lines of force originate from a positive charge and terminate at a negative charge.
2. The tangent to the line of force indicates the direction of the electric force.
3. No two electric lines of force can intersect each other.
4. When two electric lines of force proceeding in the same direction, repel each other and while proceeding in the opposite direction, attract each other.
5. The electric lines of force are always normal to the surface while starting or ending on it.

Electric Flux (Φ) and Flux density (D) :

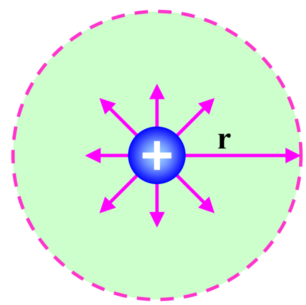
- The total number of lines of force coming out from a positive charge or the total number of lines of force terminating on a negative charge is called **electric flux**. It is denoted by **Φ** and its unit is **coulomb**.
- The total number of electric lines of force, crossing unit surface area normally is known as electric flux density (D).
- Flux density **D** = Electric flux per unit area = **Φ/A**. and its unit is **coulomb/m^2**.
- The flux density '**D**' at a given point is proportional to the intensity of electric field '**E**'.

i.e.: $D \propto E$

$$D = \varepsilon E$$

$$D = \varepsilon_0 \varepsilon_r E.$$

Electric flux due to a point charge



- Consider the sphere of a radius **'r'** surrounding a positive charge of **+q** coulomb charge with the charge at placed the center.
- Now as we know,

Electric flux = flux density x Area of sphere

$$\Phi = D \times A$$

$$\Phi = \varepsilon_0 \varepsilon_r E \times 4\pi r^2$$

$$\Phi = \varepsilon_0 \varepsilon_r \frac{1}{4\pi\varepsilon_0 \varepsilon_r} \frac{q}{r^2}(4\pi r^2)$$

$$\Phi = q$$

- Electric flux due to a point charge is equal to strength of charge '**q**' coulomb.

ELECTRIC POTENTIAL

Absolute Electric Potential:

- Absolute Electric Potential at a point is the amount of work done to move a unit positive charge from infinity to that point in the electric field. **Or**,
- The 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 electric field.
- It is scalar quantity and is denoted by '**V**'

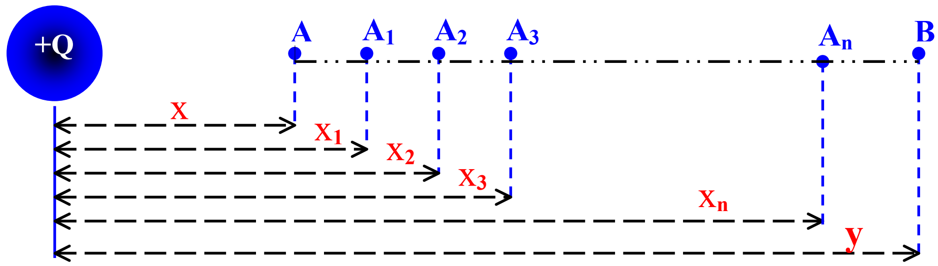
Potential difference (p.d.):

- The potential difference between any two points is the amount of work done in moving a unit positive charge from one point to the other in the electric field.
- Electric Potential difference = (Work done in joule)/(unit positive charge in coulomb)

$$V = W/q \quad \text{volt}$$

- If the work done in moving a unit charge (1C) between the two points is one joule, then the potential difference between the two points is said to be **one volt** (V).
- The S. I. unit of potential is **Joule/coulomb** or **volt**.

Potential Difference due to a point charge



- Consider a point positive charge **Q**. Consider two points **A** and **B** in the electric field of charge **+Q** at a distance **x** and **y** respectively from the charge.
- To calculate the potential difference between points **A** and **B**, the total distance between them is divided in to a number of small segments. $A_1, A_2, A_3, \ldots A_n$ are the points selected between **A** and **B**. Their distances are shown in the figure above.
- Select a pair of points **A** and A_1. Intensity of electric field at point **A** is given by

$$E_A = \frac{1}{4\pi\varepsilon_0\varepsilon_r}\frac{Q}{x^2}$$

- Intensity of electric field at point A_1 is given by

$$E_{A1} = \frac{1}{4\pi\varepsilon_0\varepsilon_r}\frac{Q}{x_1^2}$$

- Since electric intensity decreases in geometric progression as the distance increases, hence the average electric field intensity between the points **A** and A_1 is given by the geometrical means of E_A and E_{A1}. i.e.:

$$E_{AA1} = \sqrt{E_A E_{A1}}$$

$$\therefore E_{AA1} = \frac{1}{4\pi\varepsilon_0\varepsilon_r}\frac{Q}{x\,x_1}$$

Now, Potential difference $= \dfrac{\text{Work done}}{\text{Unit positive charge}} = \dfrac{\text{(Electric force) x (Distance)}}{\text{Unit positive charge}}$

$= \text{(F/Q) x Distance}$

$= \text{(Electric field) x (Distance)}$

$\therefore$ Potential diff. Between A & A_1 is written as $V_{AA1} = E_{AA1} \times D$

$$= \frac{1}{4\pi\varepsilon_0\varepsilon_r}\frac{Q}{x\,x_1}(x_1 - x)$$

$$= \frac{Q}{4\pi\varepsilon_0\varepsilon_r}\left(\frac{1}{x} - \frac{1}{x_1}\right)$$

- Similarly, the potential differences between different pairs of points can be written as

$$V_{A1A2} = \frac{Q}{4\pi\varepsilon_0\varepsilon_r}\left[\frac{1}{x_1} - \frac{1}{x_2}\right] \qquad V_{A2A3} = \frac{Q}{4\pi\varepsilon_0\varepsilon_r}\left[\frac{1}{x_2} - \frac{1}{x_3}\right] \qquad V_{AnB} = \frac{Q}{4\pi\varepsilon_0\varepsilon_r}\left[\frac{1}{x_n} - \frac{1}{y}\right]$$

- By adding the potential differences between the pairs of points, we get the potential difference between points A and B.

$$\therefore V_{AB} = V_{AA1} + V_{A1A2} + V_{A2A3} + \ldots\ldots + V_{AnB}$$

$$\therefore V_{AB} = \frac{Q}{4\pi\varepsilon_0\varepsilon_r}\left[\left(\frac{1}{x}-\frac{1}{x_1}\right)+\left(\frac{1}{x_1}-\frac{1}{x_2}\right)+\left(\frac{1}{x_2}-\frac{1}{x_3}\right)+\ldots+\left(\frac{1}{x_n}-\frac{1}{y}\right)\right]$$

$$\therefore V_{AB} = \frac{Q}{4\pi\varepsilon_0\varepsilon_r}\left[\frac{1}{x}-\frac{1}{y}\right]$$

- The absolute potential at point **A** can be determined by substituting **y = ∞** in above equation.

$$\therefore \mathbf{V_A} = \frac{1}{4\pi\,\varepsilon_0\varepsilon_r}\frac{Q}{x}$$

- In general, potential difference at any point at a distance **r** from a charge **q** is given by

$$V = \frac{1}{4\pi\ \varepsilon_0\varepsilon_r}\frac{q}{r}$$

CAPACITANCE

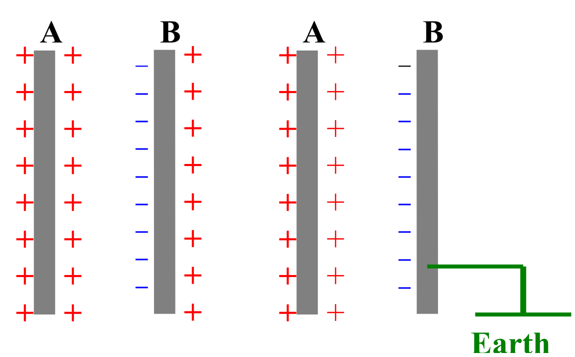
- If we give charge to any conductor, the potential of the conductor also increases as the charge on the conductor gradually increases.
- Let at any instant the charge given to the conductor is **Q** and **V** is the potential, then

$$\mathbf{Q \propto V \quad or \quad \frac{Q}{V} = C(constant)}$$

- The constant (**C**) of proportionality is known as the **capacity** or the **capacitance** of the conductor. Its value depends on the nature of the conductor and other surrounding conditions.
- Now, the capacitance of a conductor is defined as the ratio of the electric charge to the potential due to it.
- Let V=1, then C = Q; Hence the capacity of the conductor is equal to the charge required to raise the potential of the conductor by a one volt. The unit of capacity is **farad**.
- $1\,\text{farad} = \dfrac{1\,\text{coulomb}}{1\,\text{volt}}$

Princpal of capacitor:

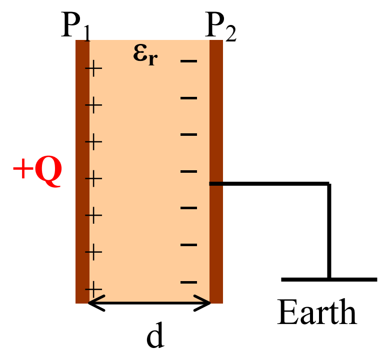
- Capacitor is an arrangement made by which large amount of charge can be stored at a small potential making it suitable and safe for use.
- Consider a conducting metal plate '**A**', which is charged to a potential **+V**.
- If a second conducting plate **B** is brought near to it, then electrostatic induction takes place. As a result of which the nearer side of the metal plate **B** gets equal negative charge whereas the farther side of the plate **B** gets equal positive charge.



- Now if the metal plate **B** is connected to the earth then the free positive charges escape to the earth. Hence the potential of the plate **B** becomes zero.
- Since all positive charges have been removed, the negative charges on metal plate **B** reduce the potential of the metal plate **A** considerable and as a result, the capacity of metal plate **A** is considerably increased. This arrangement stores the charges and is called as capacitor or condenser.

Capacitance of a parallel plate capacitor:

- The parallel plate capacitor consists of two parallel metal plates of some conducting material, separated from each other by insulated dielectric material or medium. One of the plates is given positive charge and other is earthed.
- Let the parallel plate capacitor consists of two plane plates $\mathbf{P_1}$ and $\mathbf{P_2}$ placed parallel to each other and separated from each other by distance '**d**', containing dielectric material having dielectric constant '$\boldsymbol{\varepsilon_r}$'.

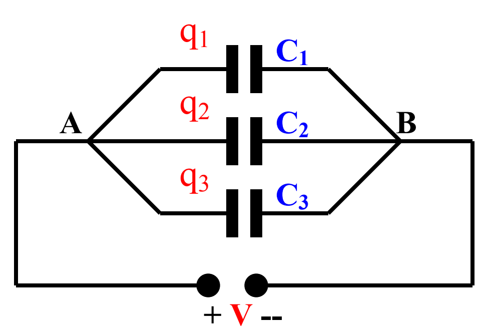


- Let, **Q** = charge on each plate, **A** = area of each plate, and **d** = distance between two plates.
- Now, Electric flux density is given by $D = \Phi/A = Q/A$
  We have $D = \varepsilon_0 \varepsilon_r E$
  $\therefore E = D/\varepsilon_0 \varepsilon_r = Q / \varepsilon_0 \varepsilon_r A$ ------------(1)
- Now, Potential difference between the plates is
  $V = E \times d = Q\,d / \varepsilon_0 \varepsilon_r A$ -------------(2)
- According to the definition of capacitance

$$C = Q/V \quad \mathbf{C} = \frac{\mathbf{Q}}{\left(\frac{\mathbf{Qd}}{\boldsymbol{\varepsilon_0 \varepsilon_r} \mathbf{A}}\right)} = \frac{\boldsymbol{\varepsilon_0 \varepsilon_r} \mathbf{A}}{\mathbf{d}}$$

Condensers in parallel

- In parallel arrangement of condensers, the positive plate of each condenser is connected to a common point; say **A** and the negative plate of each condenser is connected to another common point **B** which is earthed.



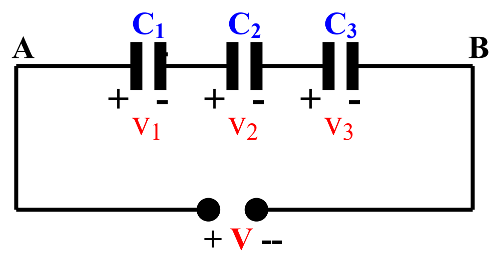
- The point **A** is given some charge, which is shared by all the capacitors depending upon their capacitance. The potential difference across the plates of each condenser is the same as that between the common points.
- Since charges are distributed, so that $\mathbf{q = q_1+q_2+q_3}$ ……………….(1)
- Now we know $C = \dfrac{q}{V}$ $\therefore CV = q$ **,** $C_1V = q_1,$ $C_2V = q_2$, $C_3V = q_3$
- putting these values in (1), We get,

$$\mathbf{Q = q_1+q_2+q_3}$$
$$C_PV = C_1V+ C_2V+ C_3V = [C_1+ C_2+ C_3]\,V$$
$$\mathbf{C_P = [C_1+ C_2+ C_3]}$$

- Where C_P is the effective capacitance, which is equal to sum of the capacitance of condensers connected in parallel.

Condensers in series

- In series the negative plate of the first condenser is connected to the positive plate of the second condenser and so on.
- In this arrangement each condenser receives the same charge. But the potential difference across the plates of each condenser is different. The total potential difference between ends of the combination is equal to the sum of the potential differences across each condenser.



- Total potential difference, $\mathbf{V = V_1 + V_2 + V_3}$ ………………(1)
- We have $C = \frac{q}{V}$, hence $V = \frac{q}{C}$

$\therefore$ We can also write $V_1 = \frac{q}{C_1}$, $V_2 = \frac{q}{C_2}$ and $V_3 = \frac{q}{C_3}$

- Putting these values in (1) we get

$$\mathbf{V = V_1 + V_2 + V_3}$$

$$\therefore \frac{\mathbf{q}}{\mathbf{C_S}} = \frac{\mathbf{q}}{\mathbf{C_1}} + \frac{\mathbf{q}}{\mathbf{C_2}} + \frac{\mathbf{q}}{\mathbf{C_3}}$$

$$\frac{\mathbf{1}}{\mathbf{C_S}} = \frac{\mathbf{1}}{\mathbf{C_1}} + \frac{\mathbf{1}}{\mathbf{C_2}} + \frac{\mathbf{1}}{\mathbf{C_3}}$$