UNIT - 2 ELECTROSTASTICS

* Concept of Charge :

Every substance is made up of atoms or molecules. Each atom is made up of electrons moving in fixed orbits around its nucleus. There are positively charged protons and nuetral neutrons inside the nucleus. Thus, every substance is made up of electrons, protons and neutrons called Fundamental Particles.

Mass of an electron is

$$M_e = 9.1 \times 10^{-31} \text{ kg}$$

Mass of a proton and a neutron is

$$M_p \cong M_n = 1.6 \times 10^{-27} \text{ kg}$$

Electric Charge :

The property of particles due to which an electric force exists between them is called the 'electric charge'.

The value of this charge $e = 1.6 \times 10^{-19}$ C.

SI unit of electric charge is coulumb.

SI unit = Collumb.

Charge of electrons $q_e = 1.6 \times 10^{-19}$ C.

Charge of protons $q_p = 1.6 \times 10^{-19}$ C.

The substance that recieves electrons becomes negatively charged and the substance which loses electrons becomes positively charged. In general, every object is neutral.

Number of electrons in electric charge,

$$n = \frac{1}{e} = \frac{1}{1.6 \times 10^{-19}}$$
$$= 6.25 \times 10^{18} \text{ electrons.}$$

Quantization of electric charge:

$$q = ne$$

where $n = 1, 2, 3, \ldots (n \in N)$.
$e = 1.6 \times 10^{-19}$ coulomb.

Numerical:
Calculate the total electric charge on an object that has 20 extra electrons.
Solution:

Number of electrons, $n = 20$
Charge of an electrone, $e = -1.6 \times 10^{-19}$ C

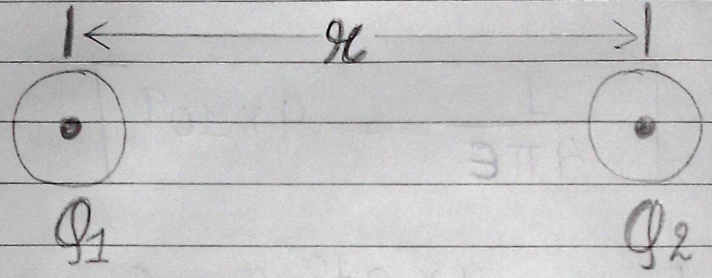
The total electrical charge of 20 electrons

$$q = ne$$
$$= (20)(-1.6 \times 10^{-19})$$
$$= -3.2 \times 10^{-18} \text{ C}$$

Laws of Electrostatics.

Law 1: Two like charges repel to each other, two unlike charges attract to each other.

Law 2:
OR
Colamb's Law OR Coulamb Inverse Square Law:



Consider two charges Q_1 and Q_2 placed at a distance r in electrostatic field, then the electrostatic force (F) experienced by two charges:

i) is directly proportional to the product of two charges Q_1 and Q_2.

$$\therefore F \propto Q_1 \cdot Q_2$$

ii) is inversely proportional to the square of distance between two charges.

$$\therefore F \propto \frac{1}{r^2}$$

$$\therefore F \propto \frac{Q_1 \cdot Q_2}{r^2}$$

$$\therefore F = \frac{k Q_1 Q_2}{r^2}$$

where k = proportionality constant

$$\therefore k = \frac{1}{4\pi\epsilon}$$

$$\therefore F = \frac{1}{4\pi\epsilon} \cdot \frac{Q_1 Q_2}{r^2}$$

$$\left[\frac{1}{4\pi\epsilon} = 9 \times 10^9 \right]$$

$$\therefore F = \frac{9 \times 9^{10} \times Q_1 \times Q_2}{r^2}$$

Suppose charge ~~of~~ Q_1 and Q_2 are two equal ~~to~~ unit charges, placed at unit distance,

$$\therefore Q_1 = Q_2 = 1\,C$$

$$\therefore r = 1\,m$$

then electrostatic force experienced by charges

$$\therefore F = 9 \times 10^9\ N.$$

Proportionality constant (k):

$$k = \frac{F \cdot r^2}{Q_1 \cdot Q_2}$$

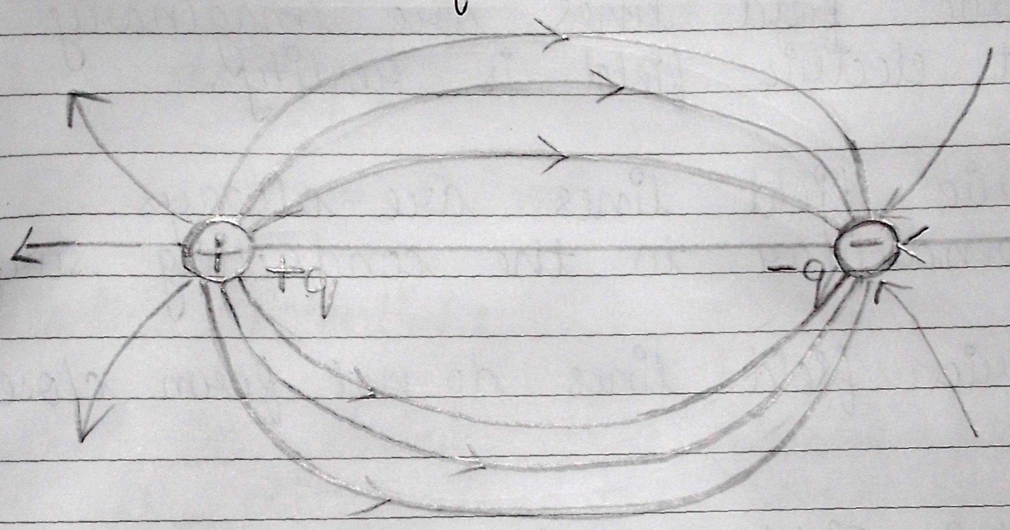
SI Unit $= Nm^2/C$

* Electric Field:

The region around an electric charge in which another charge experiences a force of attraction or repulsion is called the electric field.

SI unit = N / C

* Electric Lines of force:



The geometric representation of an electric field is called electric field lines.

⇒ Characteristics of Electric Field Lines:

i.) Electric field lines start from positive charges and end at negative charge.

ii.) The tangent drawn at any point on the electric field lines indicates the direction of the electric field at that point.

iii.) Two electric field lines never cross each other.

iv.) The distance between the electric field lines indicates the intensity of the electric field in that area.

v.) Electric field lines of the uniform electric field are mutually parallel and equidistant.

vi.) Electric field lines are imaginary but electric field is reality.

vii.) Electric field lines are always perpendicular to the conducting surface.

viii.) Electric field lines do not form closed paths.

* Electric Field Intensity:

Electric field strength or electric field intensity at a point is defined as the force experienced by a unit positive charge when placed at the point in an electric field.

SI unit = N/C

* Electric Flux:

The electric flux is a quantity

equal to the number of field lines passing through (perpendicular to) a given surface area.

SI unit = $N \cdot m^2 / C$

* Electric flux density:

Electric field lines coming from each square metre perpendicular to the electric field is called the electric flux density.

SI unit = C / m^2

* Electric Potential:

In electric field, electric potential at a point is the work done to bring a unit positive charge from infinity to that point against the field.

SI unit = Volt = $\frac{\text{Joule}}{\text{Coulomb}}$

* Electric Potential Difference:

Electric potential difference between the two points is the work done against the field in bringing a unit positive charge from one point to the other.

SI unit = Volt = $\frac{\text{Joule}}{\text{Coulomb}}$

* Capacitor:

A capacitor is a simple device that stores electric charge and electric energy. Capacitors are used to store more electrical charges or electrical energy in less space.

When dielectric material is placed between two conducting plates, capacitor is formed.

* Capacitance:

Property of capacitor to store charge is called capacitance.

If the plate of a capacitor is given charge Q and if the potential difference set up across the plates is V volt then

$$\therefore \text{Capacitance } C = \frac{\text{Electric charge } (Q)}{\text{Electric Potential } (V)}$$

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

$\therefore$ SI unit = ~~A~~ farad or F

$$\therefore 1 \text{ farad} = \frac{1 \text{ coulomb}}{1 \text{ volt}}$$

$\therefore$ 1 $\mu F = 10^{-6}$ F

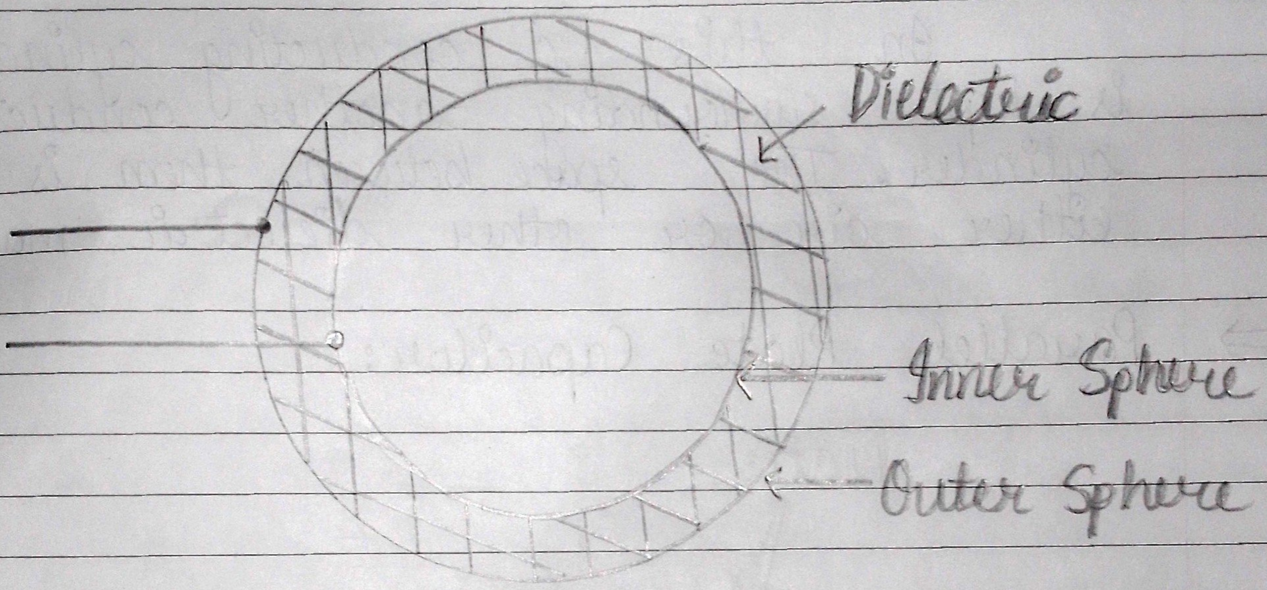
$\therefore$ 1 nF $= 10^{-9}$ F

* Types of Capacitor:

The following are three types of capacitor:

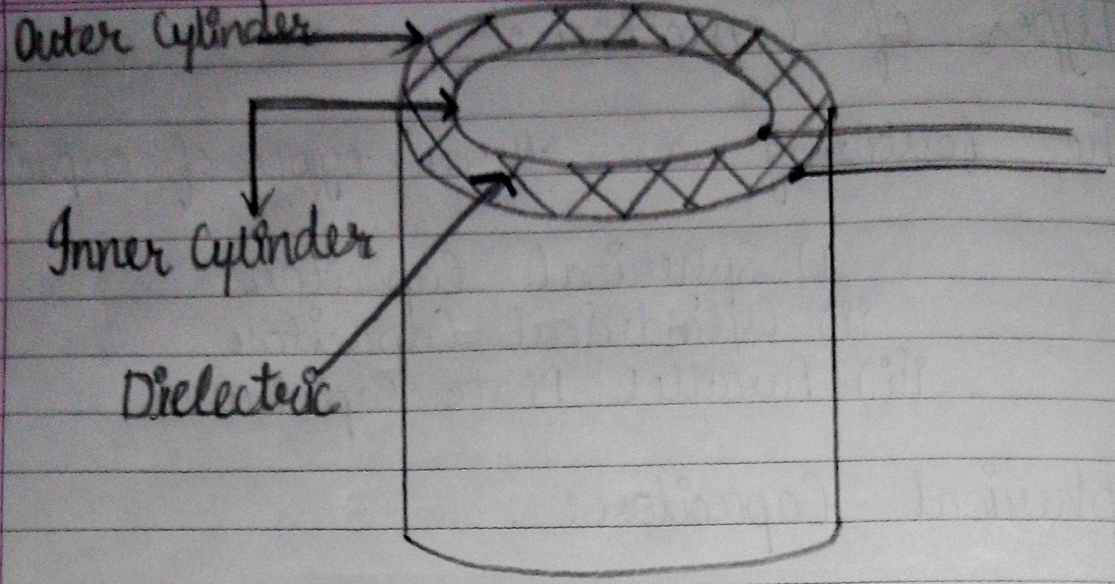
i) Spherical Capacitor
ii) Cylindrical Capacitor
iii) Parallel Plate Capacitor

⟹ Spherical Capacitor:



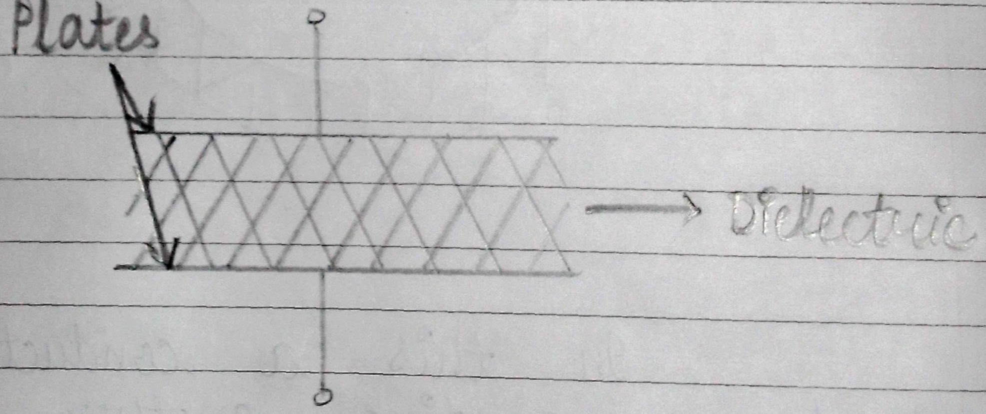
In this a conducting sphere is kept surrounding another conducting sphere. In the space between them is either air or any dielectric material.

⟹ Cylindrical Capacitor:



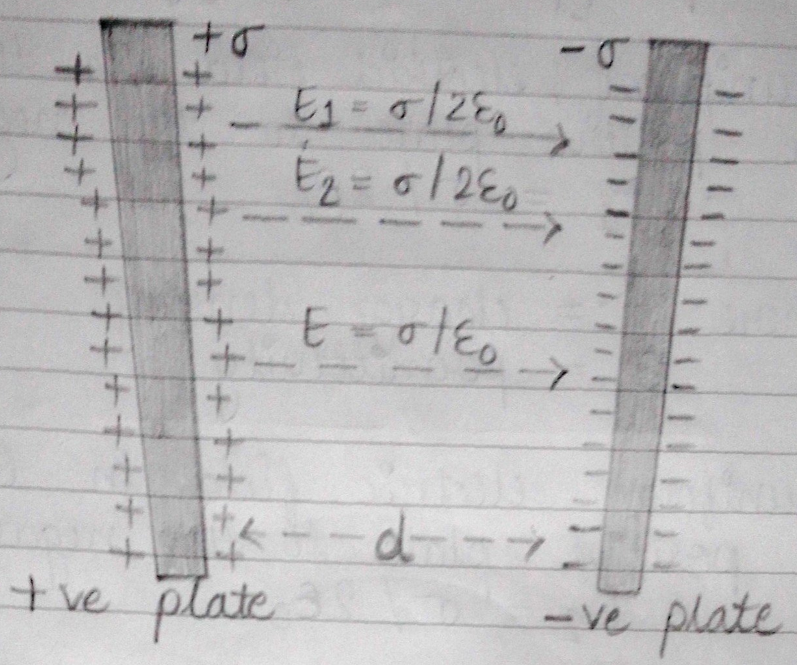
In this a conducting cylinder is kept surrounding another conducting cylinder. The space between them is either air or other dielectric material.

⇒ Parallel Plate Capacitor:



As shown in figure, two conducting plates are kept parallel to each other. Space between them is either air or other dielectric material.

* Working of Parallel Plate Capacitor and It's Capacitance:



Parallel plate capacitors are the most widely used. In a parallel plate capacitor, two parallel conducting plates of the same area (A) are seperated at very short distance (d) from each other where a dielectric medium (insulating material) is placed between two plates. Here the distance between two plates is kept very short in comparison to the dimensions.

$$\therefore d^2 << A$$

The capacitance of a parallel plate capacitor with vacuum or as a dielectric medium, as shown in figure. The charge of one plate is $+Q$ and that of the other is $-Q$. The distance between two plates (d).

∴ Area of capacitor = A m^2
∴ Capacitor plate charge = Q coulomb

The uniform electric field in the direction from positive plate to the negative plate is

$$\therefore E_1 = \sigma / 2\epsilon_0$$

where σ = charge density
ϵ = permittivity

The uniform electric field in the direction from positive plate to the negative plate is

$$\therefore E_2 = \sigma / 2\epsilon_0$$

The resultant uniform electric field

$$\therefore E = E_1 + E_2$$

$$\therefore E = \frac{\sigma}{2\epsilon_0} + \frac{\sigma}{2\epsilon_0}$$

$$= \frac{\sigma}{\epsilon_0}$$

$$= \frac{Q/A}{\epsilon_0} \quad \left(\because \sigma = \frac{Q}{A}\right)$$

$$\therefore E = \frac{Q}{A\epsilon_0}$$

In the regions on the other side of the capacitor plates, electric fields E_1 and E_2 being equal and in opposite direction, the resultant electric field becomes zero.

$$\therefore \quad E = E_1 - E_2$$

$$= \frac{\sigma}{2\varepsilon_0} - \frac{\sigma}{2\varepsilon_0}$$

$$\therefore \quad E = 0$$

The potential difference between the two plates is

$$V = E \cdot d$$

$$= \left(\frac{Q}{A\varepsilon_0}\right) \cdot d$$

$$\therefore V = \frac{Qd}{A\varepsilon_0}$$

The capacitance of the capacitor is

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

$$= \frac{\cancel{Q} \cdot A\varepsilon_0}{\cancel{Q} \cdot d}$$

$$\therefore \quad C = \frac{A\varepsilon_0}{d}$$

The capacitance of a parallel plate capacitor depends on the plate area, dielectric medium and the distance between two plates.

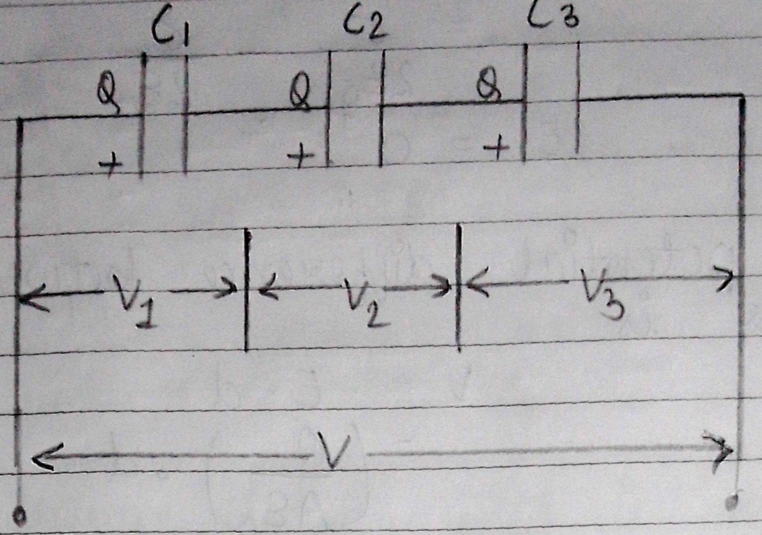
* Combinations of Capacitors:

There are two combinations:

i) Capacitors in Series

ii) Capacitors in Parallel

⇒ Capacitor in Series:



Suppose three capacitors having capacitances C_1, C_2, C_3 respectively are connected in series across V volt supply. The voltage across them are V_1, V_2, V_3 volt respectively. Since the capacitors are connected in series, charge on each is the same but the voltage drops are different.

$$\therefore V = V_1 + V_2 + V_3$$

$$\therefore \frac{Q}{C} = \frac{Q_1}{C_1} + \frac{Q_2}{C_2} + \frac{Q_3}{C_3}$$

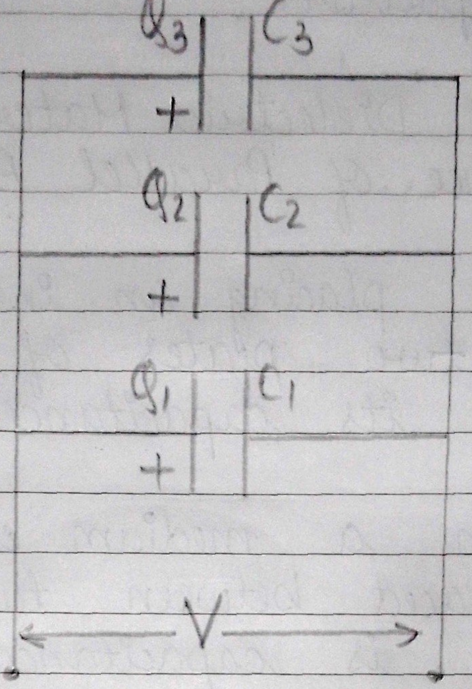
$$\therefore \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

If more capacitors are connected in series

$$\therefore \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4} + \dots$$

Thus when capacitors are connected in series, inverse of equivalent capacitance is equal to the sum of inverse of capacitances connected in series.

⇒ Capacitors in Parallel:



Suppose three capacitors of capacitance C_1, C_2, C_3, are connected in parallel across V volt supply. Since the capacitors are connected in parallel, each gets voltage V but the charge on each is different.

Let Q be the total charge and Q_1, Q_2, Q_3 be the charges on the capacitors respectively.

$$\therefore Q = Q_1 + Q_2 + Q_3$$
$$\therefore CV = C_1V + C_2V + C_3V$$
$$\therefore C = C_1 + C_2 + C_3$$

When more nos. of capacitors are connected in parallel

$$\therefore C = C_1 + C_2 + C_3 + C_4 + \dots$$

Thus, when capacitors are connected in parallel, equivalent capacitance is equal to the sum of capacitance of each capacitor.

* Effect of Dielectric Material on the Capacitance of Parallel Plate Capacitor:

When placing an insulating substance between two plates of a capacitor increases its capacitance.

When a medium of dielectric constant K is placed between two plates of a capacitor, is capacitance and hence its charge storage capacity is increased by K times.