Electrostatics (Chapter-3)

Electrostatics → Electro + statics

Electro ↓ charge

statics ↓ Stationary (Rest)

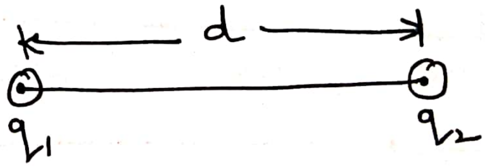
The branch of physics which deals with the charge at rest called electrostatics.

Unit of charge :- The unit for charge is Coloumb.

★ → Charge is a scalar quantity. ★

Ques 1 :- Explain coloumb's law of Electrostatics.

Ans :- **Coloumb's law** :- Acc. to this law, the force of attraction or repulsion between two charge is directly propotional to the product of two charges and inversely propotional to the square of distance between them.



Suppose q_1 and q_2 be the two point charges and let 'd' be the distance between them.

So force between the charges is given as

$$F \propto q_1 q_2 \quad \text{—(1)}$$

$$F \propto \frac{1}{d^2} \quad \text{—(2)}$$

So $F \propto \frac{q_1 q_2}{d^2}$

$$F = \frac{k\, q_1 q_2}{d^2} \quad \text{--- (3)}$$

where $k \rightarrow$ constant

$$k = \frac{1}{4\pi \epsilon_0 \epsilon_r} \rightarrow 9 \times 10^9$$

where $\epsilon_0 \rightarrow$ Absolute permittivity

$\epsilon_r \rightarrow$ Relative permittivity

for Air, $\boxed{\epsilon_r \rightarrow 1}$

So $k = \frac{1}{4\pi\epsilon_0} \rightarrow 9 \times 10^9$, Put in (3)

$$\boxed{F = \frac{q_1 q_2}{4\pi\epsilon_0 d^2}}$$

Absolute and Relative permittivity

Permittivity is the property of the medium which affects the magnitude of force existing between two charges.

Higher will be the value of permittivity, lesser will be the value of force existing between two charges.

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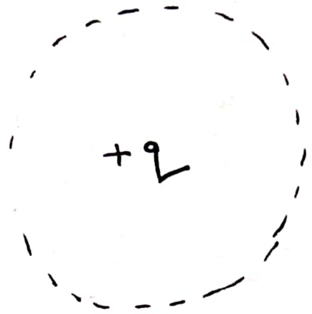
Q2. :- Define Electric field.

Ans :- Electric field is defined as the space around the charge upto which its effect can be experienced.

Mathematically Electric field is given as :-

$$\vec{E} = \frac{\vec{F}}{q} \longrightarrow N/C$$



Electric field is a vector quantity.

Unit for Electric field is Newton/Coloumb.

Ques 3 :- Define electric lines of forces. Give properties of electric lines of forces.

Ans :- Electric lines of forces :- An electric line of forces is defined as the path traced by a test charge when placed in the electric field.

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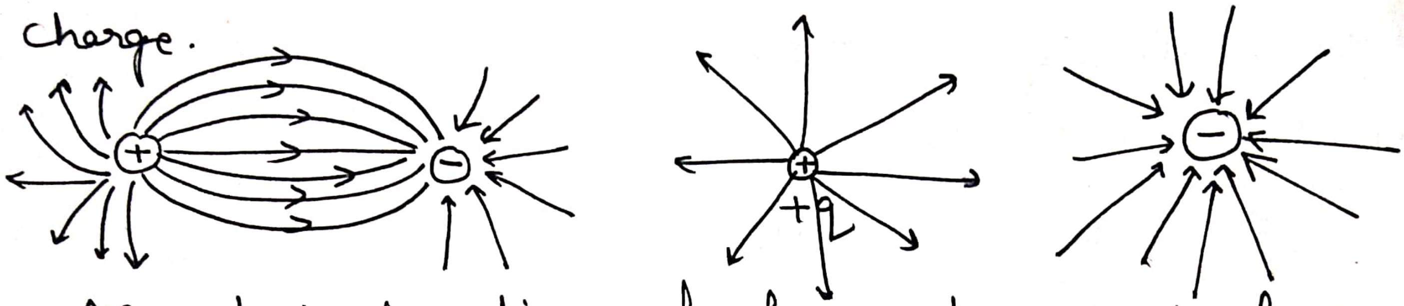
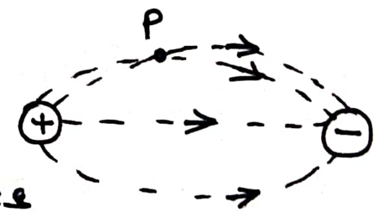
Properties of Electric lines of forces

1. An electric line of force starts from positive charge and ends on the negative charge.

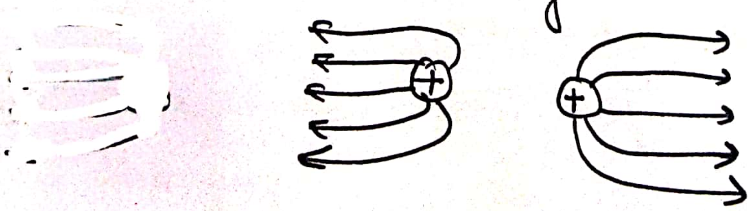


2. An electric line of force does not form a closed loop like magnetic lines of forces Because there is no electric field inside a charged body.

3. Two electric lines of forces never cross each other. The crossing of two lines means that there are two directions of force at at point 'p' which is impossible.



4. The electric lines of forces due to the same charge repel each other and due to different charge attract each other.



5. The electric lines of forces always tries to take an easy path. The electric field inside a hollow conductor is zero, so there will be no charge and no electric line of force will pass through it.

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:- Define Electric flux. ③

s :- It is defined as the total no. of electric lines of forces passing through a given surface which is held in a perpendicular direction.

Electric flux is denoted by 'ϕ'. It is a scalar quantity.

$$\phi = \oint \vec{E} \cdot \vec{ds}$$

[$\oint$ → Integration Symbol]

where $\vec{E}$ → Electric field

$\vec{ds}$ → Unit surface area

Unit for Electric flux is Nm^2/C

Ques :- What are the different kind of charge distribution?

Ans :- There are three type of charge distribution :-

1. Linear charge distribution (λ)
2. Surface charge distribution (σ)
3. Volume charge distribution (ρ)

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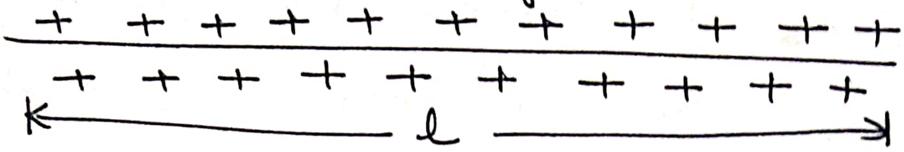
1. **Linear charge distribution (λ) :–** When the charge is uniformally distributed over a line, called linear charge distribution.



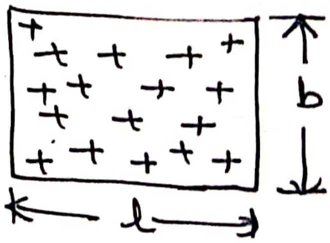
$$\lambda = \frac{q}{l} = \frac{\text{charge}}{\text{length}}$$

Unit for 'λ' $\rightarrow$ coloumb/metre

2. **Surface charge distribution (σ) :–**

When the charge is uniformally distributed over a surface, called surface charge distribution.

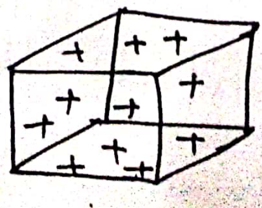
$$\sigma = \frac{q}{S} = \frac{\text{Charge}}{\text{Area}}$$



Unit for 'σ' $\rightarrow$ Coloumb/m^2

3. **Volume charge distribution (ρ) :–** When the charge is uniformally distributed over a volume, called volume charge distribution.

$$\rho = \frac{q}{V} = \frac{\text{charge}}{\text{volume}}$$



Unit for 'ρ' $\rightarrow$ Coloumb/m^3

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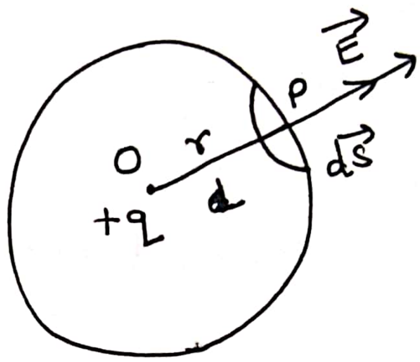
Ques :- State Gauss law in Electrostatic and explain it.

Ans. :- Gauss law :- Acc. to this law, the total electric flux through any closed surface is $\frac{1}{\epsilon_0}$ times the total charge enclosed by the surface.



Let us consider a positive charge is placed at point 'O'. The gaussian surface due to single charge is spherical. Let $\vec{E}$ be the electric field due to positive charge and $\vec{ds}$ be the unit surface area. And 'r' be radius of sphere.

Now as we know

$$\phi = \oint \vec{E} \cdot \vec{ds}$$

$$\phi = \oint E ds \cos\theta \quad \{\because \theta = 0^\circ\} \quad \{\cos 0^\circ = 1\}$$

$$\phi = \oint E ds$$

$$\phi = E \oint ds$$ {where $\vec{E}$ is constant and can be taken outside the integration

$$\phi = E 4\pi r^2$$ {$\oint ds$ = surface area of sphere $= 4\pi r^2$

$$\phi = \frac{F 4\pi r^2}{q}$$ {As $\vec{E} = \frac{\vec{F}}{q}$ }

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$$\phi = \frac{F\, 4\pi r^2}{q} \quad \text{—} (1)$$

{ Acc. to coloumbs law

$$F = \frac{q_1 q_2}{4\pi\epsilon_0 r^2}$$

{ but $q_1 = q_2 = q$

$$\left\{ F = \frac{q q}{4\pi\epsilon_0 r^2} \right\}$$

Put in eqn (1)

$$\phi = \frac{q\, q\, 4\pi r^2}{4\pi \epsilon_0 r^2 .\, q}$$

$$\boxed{\phi = \frac{q}{\epsilon_0}}$$

Hence Proved.

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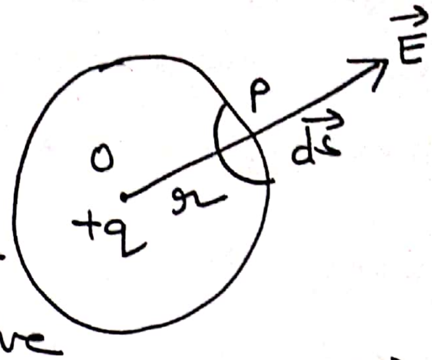
Ques :- Deduct Coloumb's law from Gauss law in electrostatic.

Ans. The Gaussian surface due to a single charge is sphere. Let us consider a unit positive charge at point 'O'. Due to this positive charge, let $\vec{E}$ be the electric field and $\vec{ds}$ be the unit area. Let 'r' be the radius of sphere.



Now $\phi = \oint \vec{E}.\vec{ds}$

$\phi = \oint E ds \cos\theta$ $\{\theta = 0^\circ\}$, $\{\cos 0^\circ = 1\}$

$\phi = \oint E ds$

$\phi = E \oint ds$

$\phi = E \, 4\pi r^2$ $\{\oint ds = 4\pi r^2\}$

$\phi = \frac{F}{q_0} . 4\pi r^2$ — (1) $\{\vec{E} = \frac{F}{q_0}\}$

Now acc. to gauss law

$\phi = \frac{q}{\epsilon_0}$ Put in (1)

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

$$\boxed{F = \frac{q q_0}{4\pi \epsilon_0 r^2}}$$

Hence Proved [we obtain coloumb's law]

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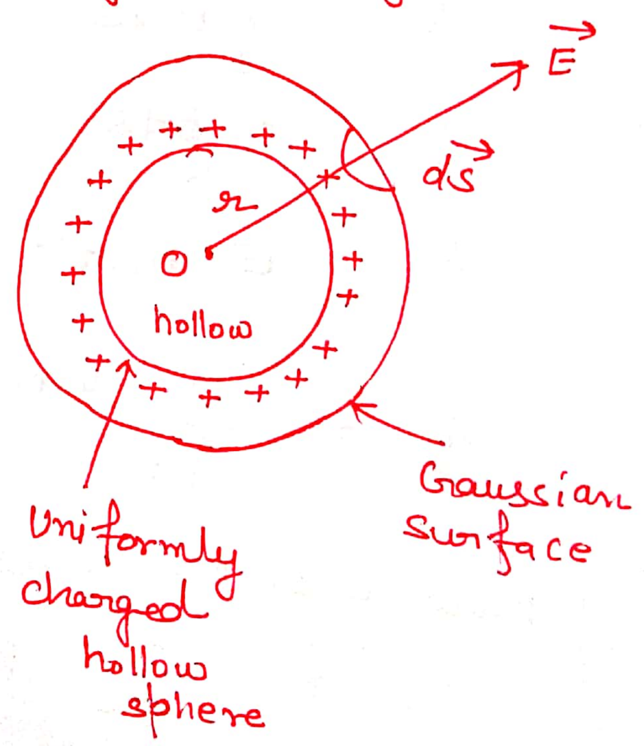
First application we have discussed already, as by using Gauss law we ~~have~~ can deduct coloumb's law. other applications of Gauss law are discussed below

1. Ques Find Electric field Intensity or Electric field due to a uniformly charged hollow sphere or shell.

Ans:- Uniformly charged hollow sphere means, their is no charge inside the hollow sphere, which means the electric field inside the hollow sphere is zero. Because if there is no charge, there will be no electric field. Now charge is only distributed over the outer surface.



Acc.

$$\phi = \oint \vec{E}\cdot\vec{ds}$$

$$\phi = \oint E\,ds\cos\theta$$

$$\phi = \oint E\,ds \quad \{\because \cos\theta = 1 \text{ as } \theta = 0^\circ\}$$

$$\phi = E\oint ds$$

$$\phi = E\,4\pi r^2 \quad \text{—(1)} \quad \{\because \oint ds = 4\pi r^2\}$$

Acc. to Gauss law

$$\phi = q/\epsilon_0$$

put in (1)

$$\frac{q}{\epsilon_0} = E\,4\pi r^2, \quad \boxed{E = \frac{q}{4\pi\epsilon_0 r^2}}$$

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where $$\boxed{E = \frac{q}{4\pi\epsilon_0 r^2}}$$

This is the value of Electric field due to uniformly charged hollow sphere.

(ii) Electric field Inside the hollow sphere.

Ans As we know that electric field inside the hollow sphere is zero, because their is no charge inside the hollow sphere.

$$\boxed{\text{So } \vec{E} = 0}$$

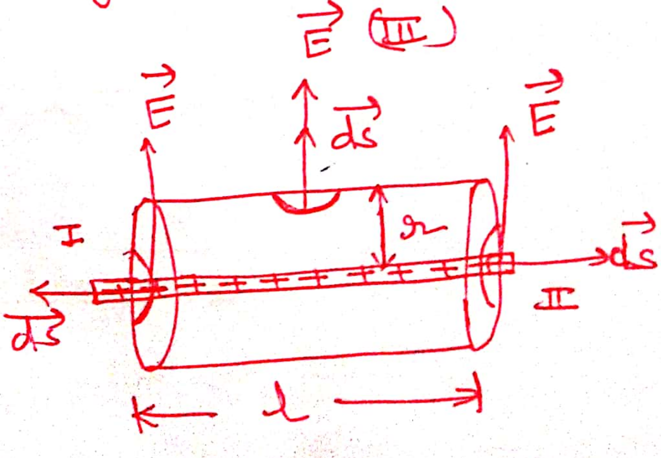
Ques :- Find Electric field Intensity due to straight charged & conductor.

Ans :- Let us consider a straight charged conductor of length 'l' having charge 'q' distributed uniformly over it.

Now Linear charge density

$$\lambda = \frac{q}{l}$$

$$\boxed{q = \lambda l}$$



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Now $\phi = \oint_{I} \vec{E}\cdot\vec{ds} + \oint_{II} \vec{E}\cdot\vec{ds} + \int_{III} \vec{E}\cdot\vec{ds}$

At surface I and II, $\theta = 90^\circ$

so $\cos 90 = 0$

At surface III, $\theta = 0^\circ$

$\cos 0 = 1$

So $\phi = \int E ds \cos 90 + \int E ds \cos 90 + \int E ds \cos 0$

$\phi = 0 + 0 + \int E ds$

$\phi = \int E ds$

$\phi = E \int ds$

$\phi = E\, 2\pi r l$ — (2) [surface area of cylinder $= ds = 2\pi r l$]

using gauss law

$\phi = q/\epsilon_0$, put in (2)

$\frac{q}{\epsilon_0} = E\, 2\pi r l$

$E = \frac{q}{2\pi \epsilon_0 r l}$

but $q = \lambda l$ (from (1))

So $E = \frac{\lambda \cancel{l}}{2\pi \epsilon_0 r \cancel{l}}$, $\boxed{E = \frac{\lambda}{2\pi \epsilon_0 r}}$

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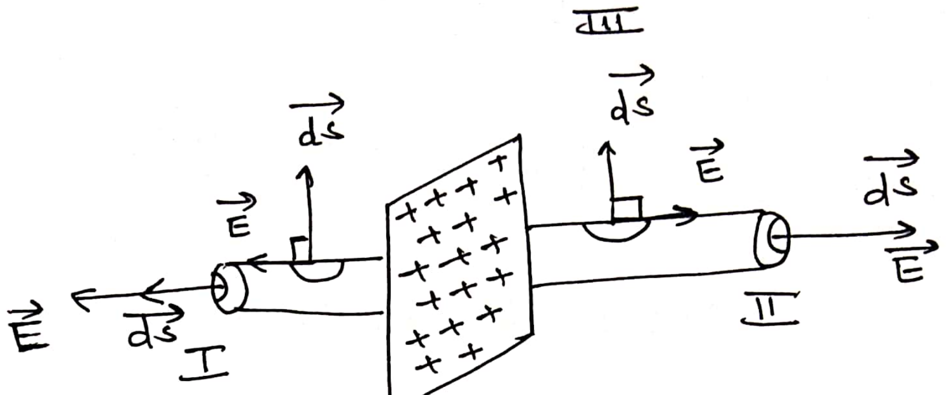
Ques :- find Electric field Intensity due to Infinite plane charged sheet.



Ans Let us consider a plane charged sheet having charge 'q'. Let 'σ' be the surface charged density. let 's' be the surface area of plane sheet.

So $\sigma = \frac{q}{s}$, $\boxed{q = \sigma s}$ (1)

Now $\phi = \int_{I} \vec{E}.\vec{ds} + \int_{II} \vec{E}.\vec{ds} + \int_{III} \vec{E}.\vec{ds}$

Now at surface I and II

$\theta = 0^\circ$, $\cos 0 = 1$

and at surface III , $\theta = 90^\circ$, $\cos 90 = 0$

so $\phi = \int E ds \cos 0 + \int E ds \cos 0 + \int E ds \cos 90$

$\phi = \int E ds + \int E ds + 0$

$\phi = 2 \int E ds$

Now $\phi = 2 \oint E ds$

$\phi = 2E \int ds$

$\phi = 2ES$ — (2) [$\int ds = S$ ↓ surface area of plane sheet]

Acc. to Gauss law

$\phi = q/\epsilon_0$

so $\frac{q}{\epsilon_0} = 2ES$

$E = \frac{q}{2\epsilon_0 S}$

but $q = \sigma S$ (from 1)

so $E = \frac{\sigma \cancel{S}}{2\epsilon_0 \cancel{S}}$

$$\boxed{E = \frac{\sigma}{2\epsilon_0}}$$

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Ques :- Define capacitor. What do you mean by Capacitance? What are the unit for capacitance?

Ans :- **Capacitor :-** It is a device which is used to 'store charge'. capacitor act as a container which is used to store charge.

Capacitance :- The property of a capacitor to store charge in it, is called capacitance.

Mathematically capacitance is given as

(Symbol)

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

{ q → charge
V → voltage }

Capacitance unit is 'Farad' or Coloumb/volt

1 microfarad = 10^{-6} farad

1 picofarad = 10^{-12} Farad

{∵ 1 micro = 10^{-6}}

{1 pico = 10^{-12}}

Types of capacitor

① **Fixed capacitor** → fixed capacitor are those whose capacitance to store charge is fixed.

② **Varriable Capacitor** → Varriable capacitor are those whose capacitance to store charge can be varry.

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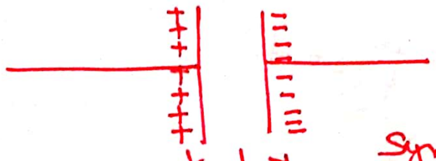
Application of capacitors

1. Capacitors are used to tune the frequency of radio receivers.
2. They are used as filters in power supplies.
3. They are used to eliminate sparking in circuits.
4. Capacitors are used in many electrical circuits.

Ques:- What are the factors affecting the capacitance of a capacitor.

Ans:- A capacitor is made of two metal plates, separated by a dielectric medium.



symbol for capacitor

Capacitance of a parallel plate capacitor is given as

$$C = \frac{A \epsilon_0}{d}$$

where $A \rightarrow$ Area of plate

$\epsilon_0 \rightarrow$ Permittivity

$d \rightarrow$ separation distance between plates

As $C = \frac{A \epsilon_0}{d}$

(1) Capacitance is directly propotional to the area of plates. More will be the area of plates, more will be the amount of charge absorb by the plates.

(2) Capacitance is directly propotional to the permittivity. So permittivity for glass, wood, mica and paper is more ~~faxa~~ as compare to air. So for glass, wood or mica capacitance will be more as compare to air.

(3) Capacitance is inversely propotional to the separation distance between the plates. More will be the separation distance, lesser will be the capacitance.

Ques :- Define Diectoric. What are the functions of Dielectoric?

Ans Dielectoric is a non-conducting medium which is used to separates the plates of capacitor. Dielectoric material is used to increase the capacitance of capacitor.

For example → Glass, mica, wax, paper, rubber etc are used as dielectric material.

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Functions of Di-electoric Material

(1) Dielectoric materials are used to separate the two large metal plates at an extremely small separation.

(2) Capacitance of capacitor can be increased by using diectoric material like we can increase the capacitance by using wax, paper, mica, rubber etc.

(3) Capacitance of a capacitor by using a dielectoric material is much more as compare to air.

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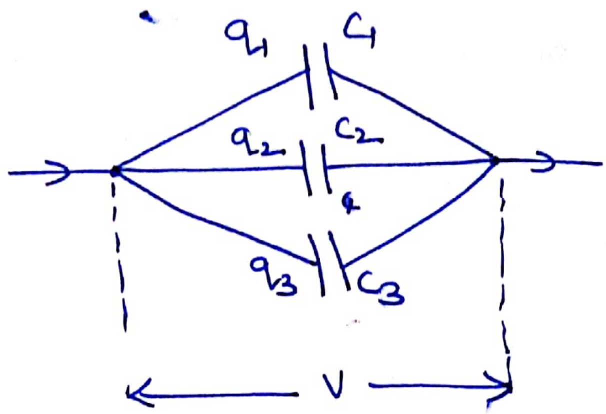
Let us consider three capacitors are connected in parallel.



Now In parallel voltage will remain same and charge will get divided.

Now total charge $q = q_1 + q_2 + q_3$ — ①

But $C = \frac{q}{V}$, $q = CV$

$C_1 = \frac{q_1}{V}$, $q_1 = C_1 V$

$C_2 = \frac{q_2}{V}$, $q_2 = C_2 V$

$C_3 = \frac{q_3}{V}$, $q_3 = C_3 V$

Put in ①

$q = q_1 + q_2 + q_3$

$CV = C_1 V + C_2 V + C_3 V$

$$\boxed{C_p = C_1 + C_2 + C_3}$$

C_p = Capacitors in parallel

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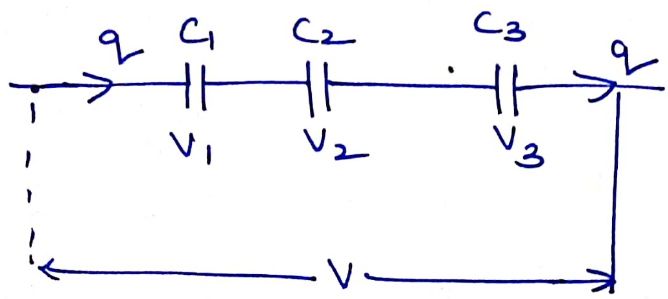
Ques :- Find an expression for capacitors in series and in parallel.

Ans :- Let us consider three capacitors are connected in series.



when capacitors are connected in series, the total charge will remain same, but voltage get divided.

So $V = V_1 + V_2 + V_3$ — (1)

As $C = \frac{q}{V}$, $V = \frac{q}{C}$

$C_1 = \frac{q}{V_1}$, $V_1 = \frac{q}{C_1}$

$C_2 = \frac{q}{V_2}$, $V_2 = \frac{q}{C_2}$

$C_3 = \frac{q}{V_3}$, $V_3 = \frac{q}{C_3}$

Put in (1)

$V = V_1 + V_2 + V_3$

$\frac{q}{C} = \frac{q}{C_1} + \frac{q}{C_2} + \frac{q}{C_3}$, $\boxed{\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$

where $C_s \rightarrow$ Capacitor in Series

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