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Electricity and Magnetism

நிலைமின்னியல்

unit-1 Electrostatics (The study of stationary electric charges (or) fields as opposed to electric current)

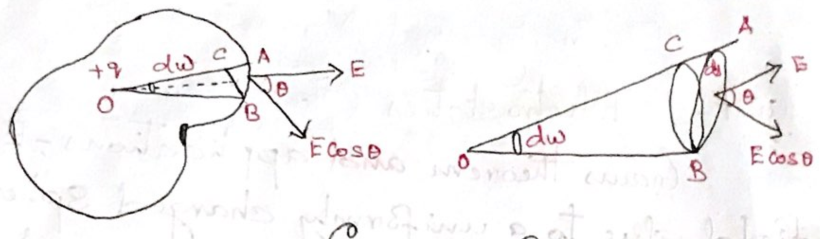
Gauss theorem and applications; Electric field due to a uniformly charged sphere - Electric field due to charged spherical and cylinder - Capacitor - Parallel plate capacitor - Cylindrical capacitor - Spherical capacitor - Energy stored in a capacitor - Loss of Energy stored in a capacitor - Loss of energy on sharing of charges.

Introduction [is a branch of physics that studies electric charges at rest]

- Electromagnetism is a branch of physical science that describes the interactions of electricity and magnetism, both as separate phenomena and as a singular electromagnetic force.
- A magnetic field is created by a moving electric current and a magnetic field can induce movement of charges (electric current)

Gauss theorem. (காஸ் தேற்றம்)

Gauss's theorem states that the total normal electrical induction (மின் புலம்) over a closed surface is equal to Σq the total charge present inside the surface.



மூடிய பரப்பிலுள்ள

Proof: Consider a closed Surface with a charge q at the point O and a small element of the Surface AB of area dS. (fig).

மின் செறிவு

Electric intensity at a point on the Surface AB

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

கூறு (உள் அடங்கிய பகுதி).

Component of the intensity perpendicular to the Surface $= E\cos\theta = \dfrac{q}{4\pi\varepsilon_0\varepsilon_r r^2}\cos\theta$.

TNEI (Total normal electric induction) over this elementary Surface அடிப்படை மேற்பரப்பு.

= Dielectric Constant × Component of the intensity perpendicular to the Surface × area of the Surface.

$$= \cancel{\varepsilon_0\varepsilon_r} \times \frac{q}{4\pi\cancel{\varepsilon_0\varepsilon_r} r^2}\cos\theta \times AB.$$

$$= \left(\frac{q}{4\pi}\right)\frac{AB\cos\theta}{r^2}.$$

$$= \frac{q\,d\omega}{4\pi} \quad \left[\frac{AB\cos\theta}{r^2} = d\omega,\right.$$ தாங்கும், the Solid angle subtended by the Surface AB at O]

TNEI over the whole surface $= \int \frac{q\,d\omega}{4\pi}$

$$= \frac{q}{4\pi}\int d\omega$$

$$= \frac{q\,4\pi}{4\pi}$$

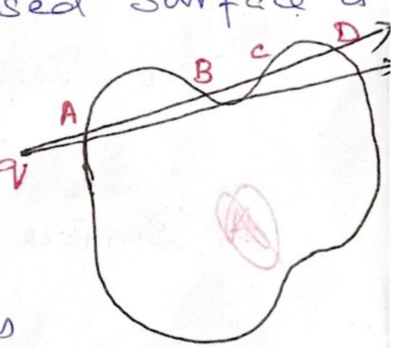
$$= q$$

(the solid angle subtended at a point inside a closed surface $= 4\pi$).

Case (i). If there are a number of charges q_1, q_2 etc. present inside the surface, the TNEI $= q_1 + q_2 + q_3 + \dots$

$$= \Sigma q.$$

Case (ii). If the charge q is outside the surface, the total normal electrical induction over the closed surface is zero.



(a). At A, TNEI inwards

$$= -\frac{1}{4\pi}\, q\, d\omega$$

(b). At B, TNEI outwards

$$= +\frac{1}{4\pi}\, q\, d\omega$$

(c). At C, TNEI inwards $= -\frac{1}{4\pi}\, q\, d\omega$

(d). At D, TNEI outwards.

$$= +\frac{1}{4\pi}\, q\, d\omega.$$

$$\therefore \frac{1}{4\pi}\Sigma q\, d\omega = 0.$$

Electric field due to a uniformly charged Sphere.

· A Spherically Symmetric charge distribution means the distribution of charge where the charge density ρ at any point depends only on the distance of the point from the centre and not on the direction.

· Consider a total charge q distributed uniformly throughout a sphere of radius R.

· Note that the sphere can't be a conductor (or), as we have seen, the excess charge will reside on its surface.

Case (i). when the point p lies outside the Sphere.

· P is a point at a distance r from the centre O.

· we have to find the electric field E at P

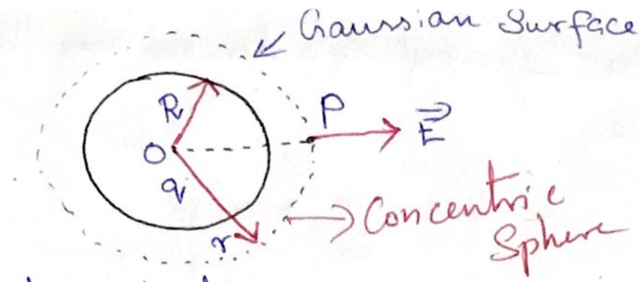
· Draw a concentric sphere (shown dotted) of radius OP with centre O.

· This is the Gaussian Surface.

· At all points of this sphere, the magnitude of the electric field is the same and its direction is perpendicular to the surface.

· Angle between E and ds is zero,

(*) (5 meters is a magnitude, North is a direction) 5 meters north is a vector quantity which has both magnitude and direction



The flux through this surface is given by

circle integral — $\oint E\cdot ds = \oint E\,ds$

$$= E(4\pi r^2)$$

surface area formula

By Gauss's law,

$$E(4\pi r^2) = \frac{q}{\varepsilon_0}$$

(or) $$E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{r^2}.$$

In vector form.

$$E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{r^2}\hat{r}$$

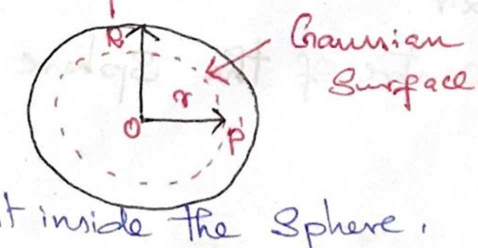
Hence, the electric field at an external point due to a uniformly charged sphere is the same as if the total charge is concentrated at its centre.

Case (ii) when the point lies on the surface.

Here, $r = R$

$$E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{R^2}$$

Case (iii). when the point lies inside the sphere.



P' is a point inside the sphere.

P' is at a distance r from the centre O.

Draw a concentric sphere of radius r ($r<R$) with centre at O.

This is the Gaussian surface.

Total charge enclosed by the Gaussian Surface.

$$q' = \frac{4}{3}\pi r^3 \rho$$

$$= \frac{\cancel{4}}{\cancel{3}}\cancel{\pi} r^3 . \frac{q}{\frac{\cancel{4}}{\cancel{3}}\cancel{\pi} R^3}$$

$$= q . \frac{r^3}{R^3}$$

Here, ρ = charge density

= charge per unit volume

$$= \frac{q}{\frac{4\pi R^3}{3}}$$

The outward flux through the Surface of the Sphere of radius r is

$$\oint E . dS = E(4\pi r^2)$$

Applying Gauss' law,

$$E(4\pi r^2) = \frac{q'}{\varepsilon_0} = \frac{q}{\varepsilon_0} . \frac{r^3}{R^3}.$$

$$\therefore E = \frac{1}{4\pi\varepsilon_0} . \frac{qr}{R^3}.$$

Thus $E \propto r$.

At the centre of the Sphere, $E = 0$.

Electric Field due to a uniform Infinite cylindrical charge.

• Let us consider that electric charge is distributed uniformly within an infinite cylinder of radius R.

• Let ρ be the charge density (charge per unit volume).

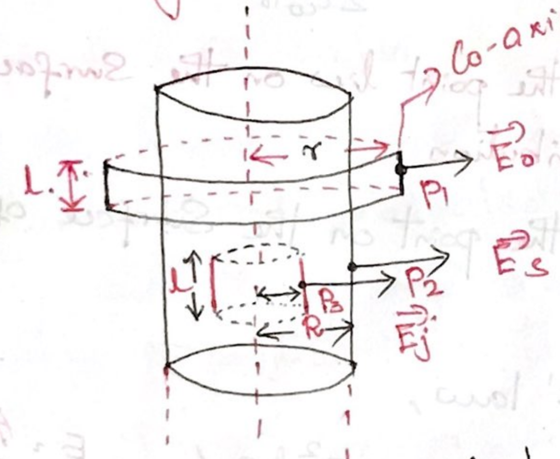
• We have to find electric field E at any point distant r from the axis lying.

(i) inside.

(ii). on the Surface.

(iii). outside the cylindrical charge distribution.

Case (i). when the point lies outside the charge distribution.



• Let P_1 be a point at a distance $r (> R)$ from the axis of the cylinder.

• Draw a co-axial cylinder of radius r and length l such that P_1 lies on the surface of this cylinder.

• From symmetry, the electric field E is everywhere normal to the curved surface and has the same magnitude at all points on it.

• The electric flux due to plane faces is zero.
• So the total electric flux is due to the curved Surface alone.

The electric flux due to curved Surface

$$= \oint E \cdot ds$$

$$= E\,(2\pi r l).$$ Surface area formula

The net charge enclosed by the Gaussian Surface $= q = \underbrace{(\pi R^2 l)}_{\text{volume formula}}\rho$

∴ by Gauss' law,

$$E\,(2\pi r l) = \frac{\pi R^2 l \rho}{\varepsilon_0}, \quad E = \frac{\cancel{\pi} R^2 \cancel{l} \rho}{2\cancel{\pi} r \cancel{l}\, \varepsilon_0}$$

$$E = \frac{\rho R^2}{2\varepsilon_0 r} \qquad \frac{\rho R^2}{2\varepsilon_0 r}$$

Case (ii). when the point lies on the Surface of charge distribution.

Let P_2 be the point on the Surface of charge distribution

By Gauss' law,

$$E\,(2\pi R L) = \pi R^2 l \rho / \varepsilon_0, \quad E = \frac{\cancel{\pi} R^{\cancel{2}} \cancel{l} \rho}{2\cancel{\pi} \cancel{R} \cancel{l}\, \varepsilon_0}$$

$$E = \frac{R\rho}{2\varepsilon_0} \qquad = \frac{R\rho}{2\varepsilon_0}$$

Case (iii). when the point lies inside the charge distribution $(r < R)$

Let P_3 be the point at a distance r $(<R)$ from the axis of the cylinder.

Consider a co-axial cylindrical surface of radius r and length l such that P_3 lies on the curved surface of this cylinder.

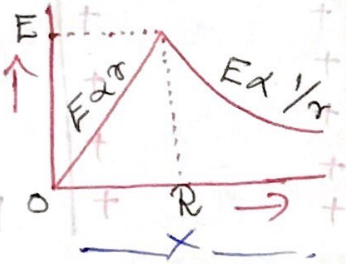
The charge q' inside this Gaussian surface $= \pi r^2 l \rho$.

By Gauss' law, $E(2\pi r l) = \frac{\pi r^2 l \rho}{\epsilon_0}$

$$\therefore E = \frac{\rho r}{2\epsilon_0}$$

$E = \frac{\cancel{\pi} r^{\cancel{2}} \cancel{l} \rho}{2 \cancel{\pi} \cancel{r} \cancel{l} \epsilon_0} = \frac{r\rho}{2\epsilon_0}$

The variation of E with r is shown in fig.



Capacitors (or) Condenser. மின்தேக்கி.

capacity of a Conductor.

If the charge on a conductor is gradually increased, its potential also increases and at any instant the charge given to a conductor is directly proportional to its potential.

$$q \propto V \quad (or) \quad q = CV \quad (or) \quad C = \frac{q}{V}$$

where, C is called the capacity (திறன்) of the conductor.

The capacity of a conductor is defined as the amount of charge that has to be given to it to raise its potential by unity.

Same

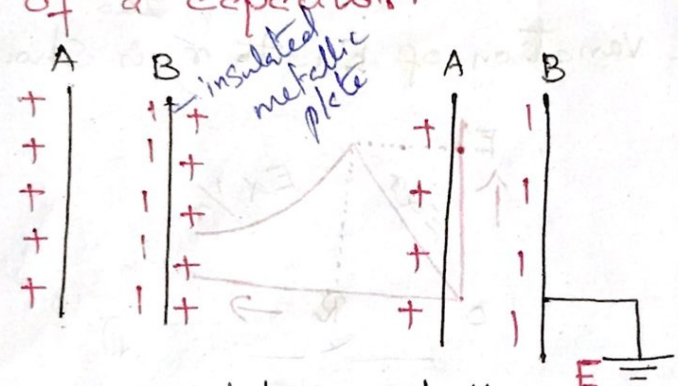
The unit of capacitance is farad.

- A Conductor has a capacitance of one farad, if a charge of 1 ~~col~~ Coulomb given to it raises its potential by 1 volt.

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

$1 pF = 10^{-12} f$

Principle of a capacitor.



Suppose an insulated metallic plate A is given a positive charge Q and its potential is V.

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

Let another insulated metal plate B be brought near A.

Negative charge is induced on that side of B which is nearer to A.

An equal positive charge is induced on the other side of B ~~which is nearer to A~~.

The negative charge on B decreases the potential of A.

The positive charge on B increases the potential of A.

But the negative charge on B is nearer to A than the positive charge on B.

So the net effect is that the potential of A decreases.

Thus the capacitance of A is increased.

The positive charge on B is neutralized by connecting the back side of B to earth (fig).

Then the potential of A decreases still further. Thus the capacitance of A is considerably increased.

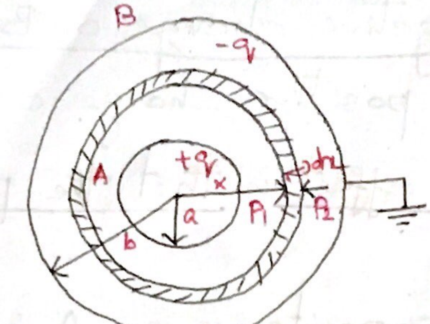
A capacitor in general consists of two conductors one positively charged and the other earthed.

The conductors are called plates.

The capacitance depends on the geometry of the conductors and the premittivity of the medium seperating them.

A capacitor is a device for storing charge.

Capacity of a Spherical capacitor (Outer Sphere earth Connected)



- A and B are two Spherical Conductor of radii a and b.
- A is charged and B is earth Connected
- Let the charge on the Conductor A be +q.
- Consider an element of radius x and thickness dx.

Electric intensity at P_1,

$$E = \frac{q}{4\pi\varepsilon_0\varepsilon_r x^2}$$

Potential difference between P_1 and $P_2 = dV$.

$$dV = -E \cdot dx$$

$$= -\frac{q}{4\pi\varepsilon_0\varepsilon_r x^2} \cdot dx$$

potential difference between A and B.

$$V = \int_b^a -\frac{q}{4\pi\varepsilon_0\varepsilon_r x^2}\, dx = -\frac{q}{4\pi\varepsilon_0\varepsilon_r}\left[-\frac{1}{a}+\frac{1}{b}\right]$$

$$= \frac{q}{4\pi\varepsilon_0\varepsilon_r}\left[\frac{1}{a}-\frac{1}{b}\right] = \frac{q}{4\pi\varepsilon_0\varepsilon_r}\left[\frac{1}{a^2}-\frac{1}{b^2}\right]$$

$$= \frac{q}{4\pi\varepsilon_0\varepsilon_r}\left[\frac{b-a}{ab}\right] = \frac{q(b-a)}{4\pi\varepsilon_0\varepsilon_r ab}$$

$\cancel{= \int \frac{1}{x^2} = \frac{1}{x} + c}$

$\int \frac{1}{x^2}\,dx$ (Apply power rule)

$\int x^n\,dx = \frac{x^{n+1}}{n+1}$ with $n=-2$

$= x^{-2+1}/_{-2+1} = \frac{x^{-1}}{-1}$

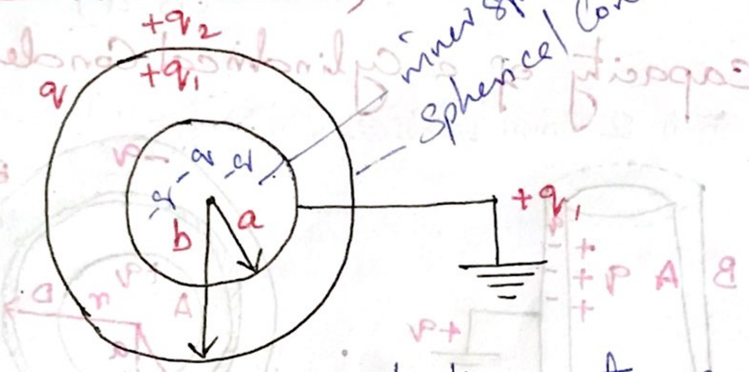
$= -\frac{1}{x} + c$

$$C = \frac{q}{V} = \frac{4\pi\varepsilon_0 \varepsilon_r ab}{b-a} \quad \text{— (i)}$$

For air medium, $C = \dfrac{4\pi\varepsilon_0 ab}{b-a}$ — (2).
$\varepsilon_r = 1$

Here, $\varepsilon_0 = 8.85 \times 10^{-12}$ coul^2/newton-m^2.

(ii). Capacity of a Spherical Condenser (inner Sphere earth connected)



- At charge $+q$ is given to the outer Conductor
- $+q_1$ is on its inner Surface and $+q_2$ is on its outer Surface.

$$q = q_1 + q_2.$$

- The $+q_1$ charge on the inner Surface of the outer Conductor induces charge $-q_1$ on the inner Sphere and $+q_1$ flows to the earth.
- The charge $+q_1$ on the inner Surface of the outer sphere and $-q_1$ on the inner sphere from a Spherical Condenser whose capacity will be $\dfrac{4\pi\varepsilon_0\varepsilon_r ab}{b-a}$
- The capacity of the outer Surface of the outer Sphere having a charge $+q_2$ and radius $b = 4\pi\varepsilon_0\varepsilon_r b$.

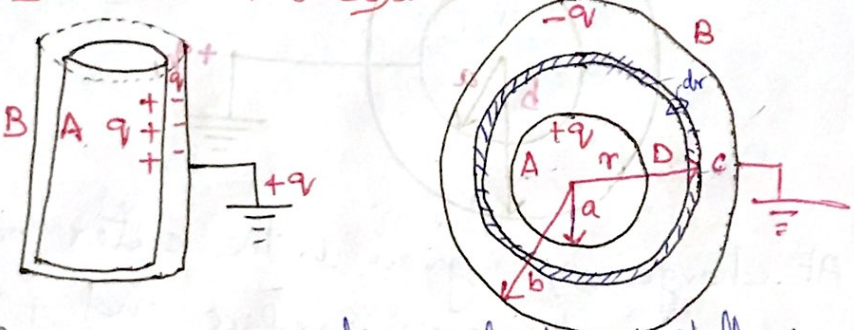
$\therefore$ Total capacity $C = 4\pi\epsilon_0\epsilon_r\left[b + \frac{ab}{b-a}\right]$

$= 4\pi\epsilon_0\epsilon_r\left[\frac{b(b-a)+ab}{b-a}\right]$ $\quad C = 4\pi\epsilon_0\epsilon_r\left[\frac{b^2 - \cancel{ab} + \cancel{ab}}{b-a}\right]$

$$= 4\pi\epsilon_0\epsilon_r\left[\frac{b^2}{b-a}\right]$$

for air medium $C = \frac{4\pi\epsilon_0 b^2}{(b-a)}$

Capacity of a Cylindrical Condenser:
நீள் உருளை மின்தேக்கியின் மின்தேக்குத்திறன்



Consider a concentric cylindrical shell of radius r and radial thickness dr.

மின்புலச் செறிவு

Electric intensity at $C = \frac{q}{2\pi\epsilon_0\epsilon_r r}$

workdone in taking a unit +ve charge from C to D. செய்யப்பட்ட வேலை நிலைமாற்றமான ஓரலகு நேர்மின்னூட்டம் புள்ளிகளுக்கிடையே

$$= \frac{q}{2\pi\epsilon_0\epsilon_r r}\,.\,dr.$$

Hence the potential difference b/w the points C and D. மின்னழுத்த வேறுபாடு

$$dV = -\frac{q}{2\pi\epsilon_0\epsilon_r r}\,dr.$$

potential difference b/w the cylinders A and B. (A B ஆகியவற்றிற்கிடையே உள்ள மின்னழுத்த வேறுபாடு

$$V = -\int_b^a \frac{q}{2\pi\epsilon_0\epsilon_r r}\,.\,dr$$

$$V = \frac{-q}{2\pi \epsilon_0 \epsilon_r} \int_b^a \frac{dr}{r}$$

$$= \frac{-q}{2\pi \epsilon_0 \epsilon_r} \left[\log_e r\right]_b^a$$

$$= \frac{-q}{2\pi \epsilon_0 \epsilon_r} \left[\log_e a - \log_e b\right]$$

$$= \frac{q}{2\pi \epsilon_0 \epsilon_r} \left[\log_e b - \log_e a\right]$$

$$V = \frac{q}{2\pi \epsilon_0 \epsilon_r} \log_e \left(\frac{b}{a}\right).$$

The capacity per unit length of the Condenser,

(ஓரலகு நீளம் கொண்ட உருளையின் மின் தேக்குத் திறனாகும்,

$$C = \frac{q}{V} = \frac{\cancel{q}}{\frac{\cancel{q}}{2\pi \epsilon_0 \epsilon_r} \log_e \left(\frac{b}{a}\right)}$$

C = charge / potential diff

$$= \frac{2\pi \epsilon_0 \epsilon_r}{2.3026 \times \log_{10}\left(\frac{b}{a}\right)}.$$

This is the capacity of the cylindrical Condenser for a length 1 metre.

Therefore, the capacity of the condenser for a length l metres.

$$= \frac{2\pi \epsilon_0 \epsilon_r l}{2.3026 \times \log_{10}\left(\frac{b}{a}\right)}$$

If the medium Consists of a compound dielectric of relative permittivity ϵ_{r_1} and ϵ_{r_2} then the capacity of such a condenser per unit length.

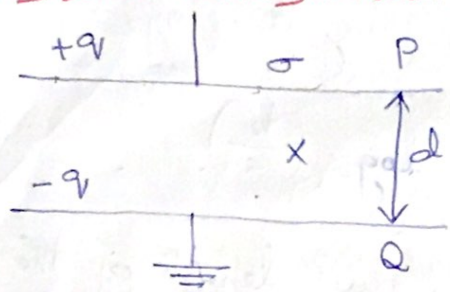
$$C = \frac{1}{\left(\frac{\log_e \frac{r_1}{a}}{2\pi \epsilon_{r_1} \epsilon_0} + \frac{\log_e \frac{r_2}{r_1}}{2\pi \epsilon_{r_2} \epsilon_0} + \right)}$$

$$C = \frac{2\pi\varepsilon_0}{\left(\frac{\log_e\left(\frac{r_1}{a}\right)}{\varepsilon_{r_1}} + \frac{\log_e\left(\frac{r_2}{r_1}\right)}{\varepsilon_{r_2}} + \dots\right)}$$

Parallel plate capacitor. (இணைத் தகடு மின்தேக்கி)

(i). capacity of a parallel plate capacitor

இணைத் தகடு மின்தேக்கியின் திறன்.



- P and Q are two parallel plates of a capacitor separated by a distance of d.
- The area of each plate is A.
- The plate P is charged and Q is earth connected.
- The charge (மின்னூட்டம்) on P is +q and surface density of charge (பரப்பு மின்னூட்ட அடர்த்தி) $= \sigma$

charge = area × surface density

$\therefore q = A\sigma$

The electric intensity at the point x, $E = \frac{\sigma}{\varepsilon_0 \varepsilon_r}$

Potential difference (மின்னழுத்த வேறுபாடு) b/w the plates P and Q,

$$\int dV = \int_d^0 -E\,dx$$

$$V = \int_d^0 -\frac{\sigma}{\varepsilon_0\varepsilon_r}\,dx$$

$\int dx$ is $x+c$

$$= -\frac{\sigma}{\varepsilon_0\varepsilon_r}\left[x\right]_d^0$$

$$= -\frac{\sigma}{\varepsilon_0\varepsilon_r}\left[0-d\right]$$

$$= \frac{\sigma d}{\varepsilon_0\varepsilon_r}$$

$$= \frac{\sigma d}{\varepsilon_0\varepsilon_r}.$$

∴ capacity of the Condenser,

$$C = \frac{\text{charge}}{\text{Potential difference}}$$

$$= \frac{A\cancel{\sigma}}{\frac{\cancel{\sigma} d}{\varepsilon_0 \varepsilon_r}}$$

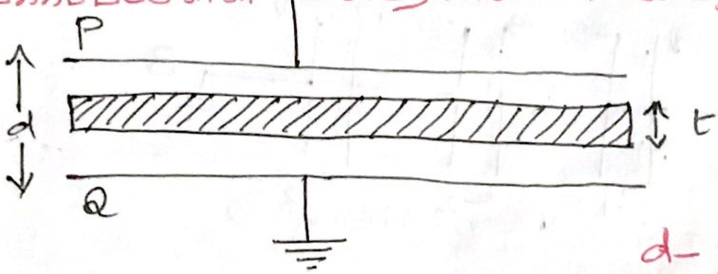
$$= \frac{\varepsilon_0 \varepsilon_r A}{d} \text{ farads.}$$

For air medium, $\varepsilon_r = 1$

$$C = \frac{\varepsilon_0 A}{d} \text{ farads.}$$

(ii). Capacity of a parallel plate Condenser with a dielectric slab in between.

இணைத் தகடுகட்கிடையே பகுதி மின்கடத்தாப் பாளம் வைக்கப்பட்டுள்ள மின்தேக்கியின் மின்தேக்குத் திறன்



d – distance
இடைவெளி

- Between the two parallel plates P and Q, a dielectric slab of uniform thickness (தடிமன்) t and dielectric Constant ε_r is placed.

ஒப்புமை விடுதிறன்

Thickness of the dielectric slab = t

மின் கடத்தா பொருள் மாறிலி

Dielectric Constant of the Slab = ε_r

Thickness of the air portion = $(d-t)$

Equivalent air thickness = $\frac{t}{\varepsilon_r}$

—x—

Effective air distance b/w the plates

$$P \text{ and } Q = \left(d - t + \frac{t}{\varepsilon_r}\right)$$

In rationalised MKS units (or) SI units

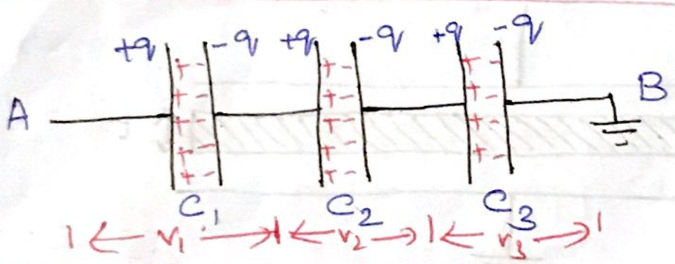
Capacity of the capacitance

$$C = \frac{\varepsilon_0 A}{\left[d - t + \frac{t}{\varepsilon_r}\right]} \text{ farads.}$$

If there are a number of dielectric slabs of thickness $t_1, t_2, t_3 \dots$ and dielectric constants $\varepsilon_{r_1}, \varepsilon_{r_2}, \varepsilon_{r_3} \dots$ respectively, then the total capacity of such a condenser,

$$C = \frac{\varepsilon_0 A}{\left[d - (t_1 + t_2 + t_3 + \dots) + \left(\frac{t_1}{\varepsilon_{r_1}} + \frac{t_2}{\varepsilon_{r_2}} + \frac{t_3}{\varepsilon_{r_3}} + \dots\right)\right]} \text{ farads}$$

Condensers in Series and in parallel.



(i) Series. தொடர்

· Three condensers of capacity C_1, C_2 and C_3 are joined in series.

· A charge $+q$ is given to the point A and B is earth connected.

· Potential difference across $C_1 = V_1$

· " " " $C_2 = V_2$

· " " " $C_3 = V_3$

Resultant potential difference (மின்னழுத்த வேறுபாடு) between the points A and B.

$$V = V_1 + V_2 + V_3 \quad \text{——} (1)$$

Equivalent Condenser will have a charge q on the plates and potential difference between the plates = V

Hence the capacity of the equivalent Condenser

$$= C_S = \frac{q}{V}$$

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

and $V_1 = \frac{q}{C_1}$, $V_2 = \frac{q}{C_2}$, $V_3 = \frac{q}{C_3}$

Substituting these values in (i)

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

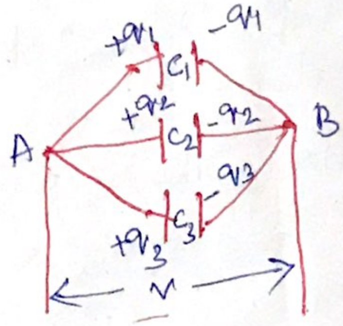
$$\therefore \frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}.$$

when a number of capacitors are Connected in Series, the reciprocal of the resultant capacity is equal to the Sum of the reciprocal of the capacities of the individual capacitors.

(ii). Parallel. இணை

- Three Condensers of capacity C_1, C_2 and C_3 are joined in parallel.
- A charge +Q is given to the point A and it gets distributed among the three Condensers depending upon their capacities.
- The potential difference across each Condenser is the Same.
- The point B is earth Connected.

The potential difference between the points A and B = V



$$Q = q_1 + q_2 + q_3$$

But $Q = C_P V$.

$$q_1 = C_1 V$$
$$q_2 = C_2 V$$
$$q_3 = C_3 V.$$

$$C_P V = C_1 V + C_2 V + C_3 V$$

$$C_P = C_1 + C_2 + C_3$$

When a number of condensers are connected in parallel, the resultant capacity is equal to the sum of the capacities of the individual condenser

Energy stored in a charged capacitor

Let q' be the charge

- V' the potential difference established between the plates of the capacitor at any instant during the process of charging.
- If an additional charge dq' is given to the plates, the work done by the battery is given by

$$dW = V' dq'$$
$$= \left(\frac{q'}{C}\right) dq' \quad \left(\because V' = \frac{q'}{C}\right)$$

Total work done to charge a capacitor to a charge q is

$$W = \int dW = \int_0^{q} \frac{q'}{C}\, dq'$$
$$= \frac{1}{2} \frac{q^2}{C}$$

This work done is stored as electrostatic potential energy in the capacitor.

$$\therefore U = \frac{1}{2}\frac{q^2}{c}$$

$$= \frac{1}{2}cv^2 \quad (\because q = cv)$$

The energy can be recovered if the capacitor is allowed to discharge.

Energy Density

Consider a parallel plate capacitor of area A and plate separation d.

Energy of the capacitor $= U = \frac{1}{2}cv^2$

$$= \frac{1}{2}\left(\frac{\varepsilon_0 A}{d}\right)v^2$$

Volume of the space b/w the plates = Ad.

Energy density u is the potential energy per unit volume,

$$u = \frac{U}{Ad} = \frac{1}{2}\left(\frac{\varepsilon_0 A}{d}v^2\right) \times \frac{1}{Ad}$$

$$= \frac{1}{2}\varepsilon_0\left(\frac{V}{d}\right)^2$$

$$u = \frac{1}{2}\varepsilon_0 E^2 \quad (V/d = E)$$

Thus we can associate an electrostatic energy density $u = \frac{1}{2}\varepsilon_0 E^2$ with every point in space where an electric field E exists.

Electric field at any point in the air space between the plates $\} E = \frac{\sigma}{\varepsilon_0}$

" " ~~b/w~~ in the slab $= E' = \frac{\sigma}{\varepsilon_r \varepsilon_0}$

The potential difference V b/w the plates is the workdone in carrying a unit +ve charge from one plate to other in the field E over a length $(d-t)$ and in the field E' over a length t.

$$V = E(d-t) + E't = \frac{\sigma}{\varepsilon_0}(d-t) + \frac{\sigma}{\varepsilon_r \varepsilon_0} t$$

$$= \frac{\sigma}{\varepsilon_0}(d-t) + \frac{\sigma}{\varepsilon_r \varepsilon_0} t$$

$$= \frac{\sigma}{\varepsilon_0}\left[(d-t) + \frac{t}{\varepsilon_r}\right]$$

The charge on the plate $p = q = \sigma A$

$$C = \frac{q}{V} = \frac{\sigma A}{\frac{\sigma}{\varepsilon_0}\left[(d-t) + \frac{t}{\varepsilon_r}\right]}$$

$$= \frac{\varepsilon_0 A}{\left[(d-t) + \frac{t}{\varepsilon_r}\right]}$$

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Energy Stored in a capacitor

- The capacitor is a charge storage device.
- work has to be done to store the charges in a capacitor.
- this work done is stored as electrostatic potential energy in the capacitor.
- Let q be the charge.
- V be the potential difference between the plates of the capacitor.
- If dq is the additional charge given to the plate, then work done is $dw = V dq$

$$dw = \frac{q}{c} dq \quad \left(V = \frac{q}{c}\right).$$

Total work done to charge a capacitor is

$$w = \int dw = \int_0^q \frac{q}{c} dq \qquad \int q\, dq = \frac{q^2}{2} + c$$

$$= \frac{1}{2}\frac{q^2}{c}$$

This work done is stored as electrostatic potential energy (U) in the capacitor.

$$U = \frac{1}{2}\frac{q^2}{c} \quad (q = cV)$$

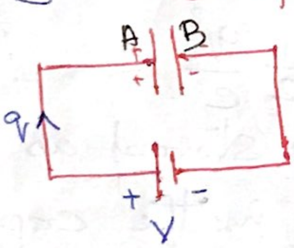
$$= \frac{1}{2}\frac{\cancel{c^2}V^2}{\cancel{c}} = \frac{1}{2}cV^2$$

This energy is recovered if the capacitor is allowed to discharge.

Loss of energy Stored in capacitor

- whenever there is transformation of energy Some energy is lost in form of heat.
- To Identify the loss of energy on charging a capacitor, a capacitor having capacitance (C) is connected to a source of energy (battery).
- Let 'v' be the potential difference across terminals of the battery and 'q' be the amount of charge flowing through it towards the plate A of capacitor.
- As the charge reaches the capacitor, plate A acquires (obtain) ~~+v~~ positive charge and due to induction plate B acquires (obtain) equal amount negative charge thereby developing the same potential difference (V) as that of battery

(Same potential difference)



potential at capacitor = V

If q is the charge Coming out of battery and V is its potential difference.

Then, potential energy given by battery $= U = qV$