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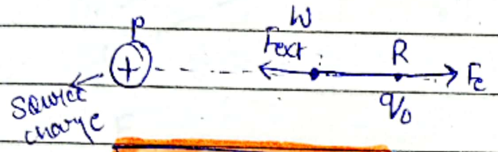
Ch-2

Electrostatic Potential and Capacitance.

* Electrostatic Potential.

⇒ It is defined as work-done per unit test charge & is characteristic of the electric field associate with the charge configuration.



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

$$V = \frac{U_P - U_R}{q_0}$$

$$V = \frac{\Delta U}{q_0}$$ → electric potential energy

SI unit : volt or J/C

D.F $= \frac{ML^2T^{-2}}{AT} = [ML^2T^{-3}A^{-1}]$

* Potential energy

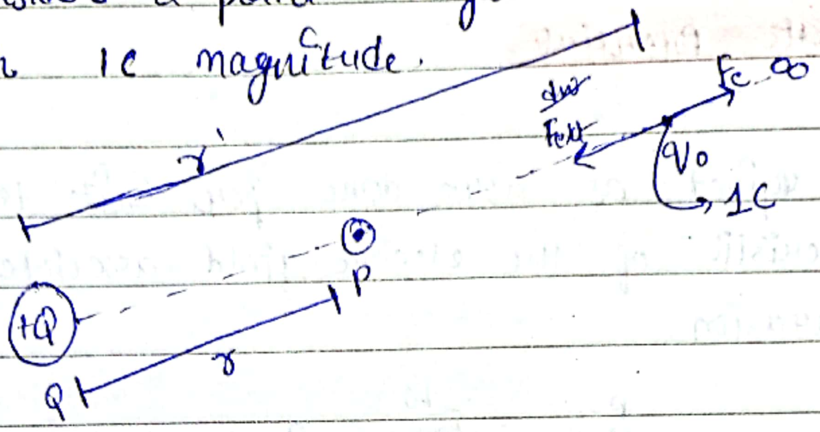
⇒ Potential energy of a charge q at a point [in the presence of field due to any charge configuration] is the work done by the external force [equal & opposite to the electric force] in bringing the charge q from infinity to that point.

SI unit : Joule

* **Electric Potential** : It is the amount of work done per unit charge in moving the charge from infinite to a point against the electrostatic force.

* **Derive the expression of electric potential energy due point charge**

let us consider a point charge 'Q' and a test charge q_0 with 1C magnitude.



$F_{ext} = -F_c$

Now,

Work done $(dW) = \int F_{ext}\,dx$

$\Rightarrow dW = \int -F_c\,dr'$

$dW = \int_{\infty}^{r} \frac{-KQ.q_0}{(r')^2}\,dr'$

$dW = -KQ\int_{\infty}^{r} (r')^{-2}\,dr'$

$W = KQ\left[(r')^{-1}\right]_{\infty}^{r}$

$W = KQ\left[\frac{1}{r'}\right]_{\infty}^{r}$

$W = KQ\left[\frac{1}{r} - \cancel{\frac{1}{\infty}}^{\,0}\right]$

$$\boxed{W = \frac{KQ}{r}}$$

$V = \frac{1}{4\pi\epsilon_0}\frac{Q}{r}$

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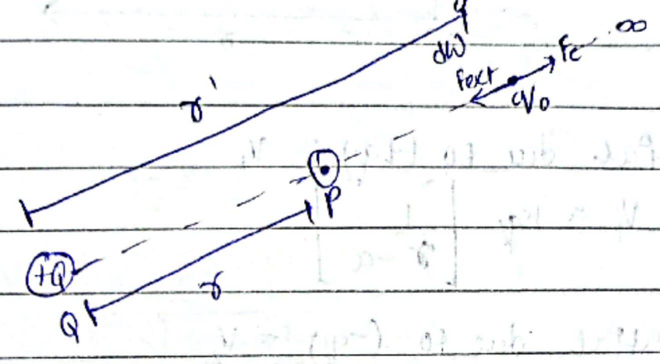
* **Derive the expression of electric potential due to point charge?**

Let us consider a point charge 'Q' and a test charge (q_0)



$F_{ext} = -F_e$

Now,

Work done $(dW) = \int F_{ext}\, dx$

$dW = \int -F_e\, dr'$

$dW = \int_{\infty}^{r} \frac{-KQ.q_0}{(r')^2} dr'$

$dW = -KQq_0 \int_{\infty}^{r} (r')^{-2} dr'$

$W = KQq_0 \left[(r')^{-1}\right]_{\infty}^{r}$

$W = KQq_0 \left[\frac{1}{r'}\right]_{\infty}^{r}$

$W = KQq_0 \left[\frac{1}{r} - \cancel{\frac{1}{\infty}}\right]$

$$\boxed{W = \frac{KQq_0}{r}}$$

$W = \frac{1}{4\pi\epsilon_0} \frac{Qq_0}{r}$

Now, we know that $V = \frac{W}{q_0}$

$V = \frac{\left(\frac{KQq_0}{r}\right)}{\cancel{q_0}}$, $\boxed{V = \frac{KQ}{r}}$ or $\frac{Q}{4\pi\epsilon_0 r}$

S.I unit = J/C or volt

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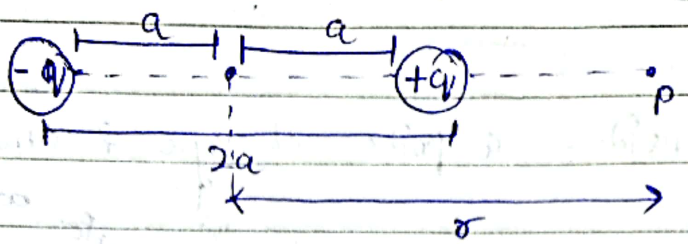
* **Electric potential due to dipole [axial]**



Potential due to $(+q) = V_1$

$$V_1 = Kq\left[\frac{1}{r-a}\right]$$

Potential due to $(-q) = V_2$

$$V_2 = -Kq\left[\frac{1}{r+a}\right]$$

Total electric dipole potential

$$V = V_1 + V_2$$

$$V = Kq\left[\frac{1}{(r-a)} - \frac{1}{r+a}\right]$$

$$V = Kq\left[\frac{(r+a)-(r-a)}{(r-a)\,(r+a)}\right]$$

$$V = Kq\left[\frac{2a}{r^2-a^2}\right]$$

$$V = \frac{K[q \times 2a]}{r^2-a^2}$$

$$\boxed{V = \frac{K.P}{r^2-a^2}}$$

If $r >> a$ [for short dipole].

$$\boxed{V = \frac{K.P}{r^2}}$$

$$\boxed{V = \frac{1}{4\pi\epsilon_0}\,\frac{P}{r^2}}$$

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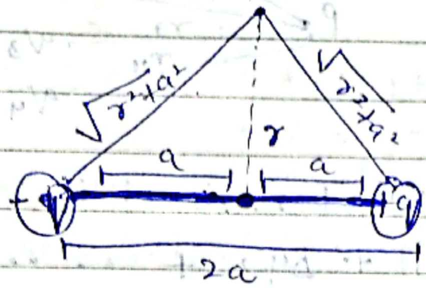
* Electric potential due to dipole on equitorial plane



$$V_1 = \frac{-kq}{\sqrt{r^2-a^2}}$$

$$V_2 = \frac{kq}{\sqrt{r^2-a^2}}$$

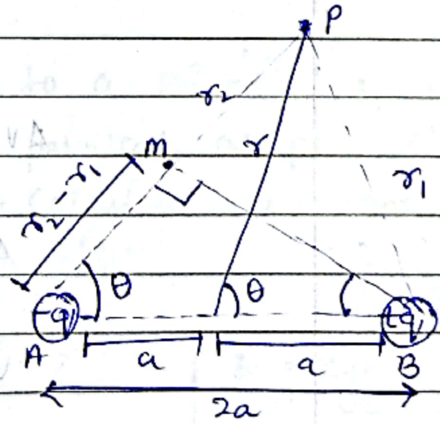
$$V = V_1 + V_2$$

$$V = \frac{-\cancel{kq}}{\sqrt{r^2-a^2}} + \frac{\cancel{kq}}{\sqrt{r^2-a^2}}$$

$$\boxed{V_{equitorial} = 0}$$

Imp *

Derive the expression for electric potential due to dipole at any point.



Potential due to (-q)

$$V_1 = \frac{-kq}{r_2}$$

$$V_2 = \frac{kq}{r_1}$$

Net potential [V]

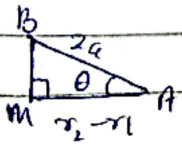
$$V = V_1 + V_2$$

$$V = kq\left[\frac{-1}{r_2} + \frac{1}{r_1}\right]$$

$$V = kq\left[\frac{-r_1 + r_2}{r_1 \cdot r_2}\right]$$

$$V = kq\left[\frac{r_2 - r_1}{r_1 \cdot r_2}\right]$$

Now,



$$r_2 - r_1 = 2a\cos\theta$$

$$V = kq\left[\frac{2a\cos\theta}{r_1 r_2}\right]$$

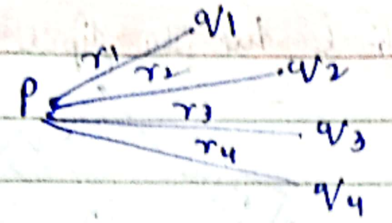
$$r_1 \approx r_2 = r$$

$$V = \frac{kq\, 2a\cos\theta}{r^2}$$

$$\boxed{V = \frac{kP\cos\theta}{r^2}}$$

$$V = \frac{1}{4\pi\epsilon_0} \times \frac{P\cos\theta}{r^2}$$

* **Superposition**



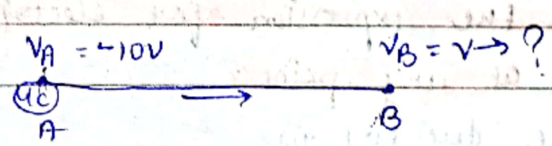
$$V_{net} = V_1 + V_2 + \dots + V_n$$

$$V_{net} = \frac{Kq_1}{r_1} + \frac{Kq_2}{r_2} + \dots + \frac{Kq_n}{r_n}$$

$$V_{net} = K\left[\frac{q_1}{r_1} + \frac{q_2}{r_2} + \dots \frac{q_n}{r_n}\right].$$

Q. If 100 J of work has to be done in moving an electric charge of 4C from a place where potential is −10 volt to another place where potential is V volt. Find the value of V ?

Ans. $W = 100\,J$ $\qquad q = 4C$



$$\Delta V = V_B - V_A = V - (-10)$$
$$= V + 10$$

$$\Delta V = \frac{W}{q}$$

$$V + 10 = \frac{100^{25}}{4_1}$$

$$V = 25 - 10$$

$$\boxed{V = 15V}$$

Q. Determine the electric potential at surface of a gold nucleus [79 4] (gold mass) the radius is 6.66×10^{-15} m. $q/p = 1.6 \times 10^{-19}C$
Find Potential.

constant [same] potential

* Equipotential Surface

=) An equipotential surface is a imaginary surface where constant value of potential at all point of the surface.

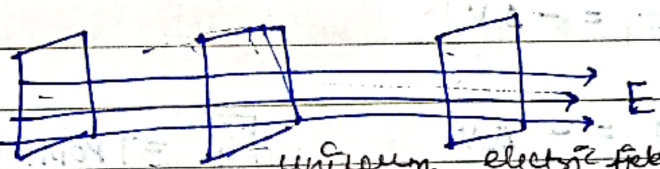
$$V = \text{constant}$$

$$\Delta V = 0 \qquad \Delta V = 0$$

=) The electric field at every point is normal to the equipotential surface passing through that point.

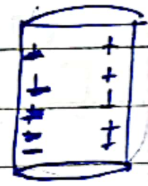
=) For any ~~charge~~ charge configuration equipotential surface through a point is normal to the electric field at that point.

①



uniform electric field

③ linear charge



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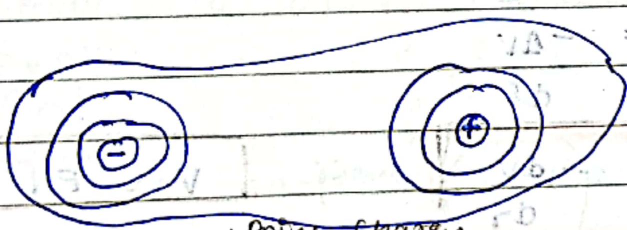

Point charge.

These three are types of equipotential surface

* Properties of equipotential surface

=) There is no work done on moving at equipotential surface

=) Two equipotential surface never intersect each other. because at point of intersection there will be two values which is not possible.

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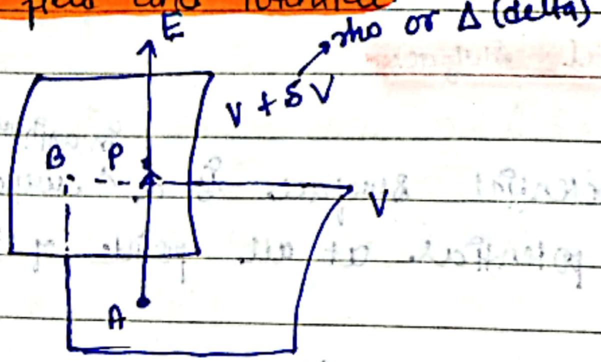
* Relation b/w field and Potential



=) The work is equal to the potential difference.

→ Consider two closely spaced equipotential surfaces A and B with Potential values V and V + ΔV

$$V_{BA} = V - V - \Delta V$$
$$V_B = -\Delta V$$

$$\Delta w = -\Delta V \qquad [q = 1 \text{ Point charge}]$$
$$E dl = -\Delta V$$
$$E = \frac{-\Delta V}{dl}$$

$$\boxed{E = -\frac{dV}{dr}} \quad \text{or} \quad \boxed{V = Ed}$$

→ Potential gradient.

(i) E.F is in the direction in which the potential decreases steepest.
(ii) Its magnitude is given by the change in the magnitude of potential per unit displacement normal to the equipotential surface at the point.

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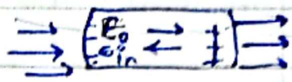
* Dielectric [It is a kind of Dielectric].

=) These are non - conducting substance.

* Behaviour of dielectric in external electric field.



$E_0 + E_{in} \neq 0$

=) It reduces internal energy but not be zero

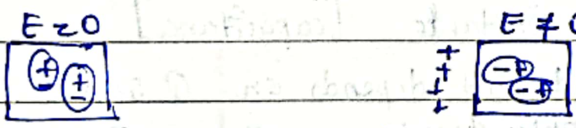
=) The opposing field so induced does not exactly cancel the external field

=) In conductor $E_0 + E_{in} = 0$ can be zero but not in Dielectric.

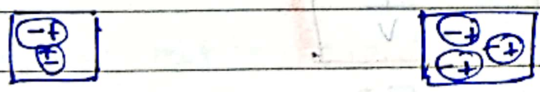
* Polar and Non-Polar [Types of Dielectric]

=) Polar $\neq 0$ Dipole moment [HCl, H_2O]

=) Non-Polar $= 0$ Dipole moment [H_2, CO_2]



(a) Non-polar molecules.



(b) Polar molecule

=) In external the +ve & -ve charge of a non pole molecules are displaced in opp. direction

=) A dielectric polar molecules also develop net dipole in an external field.

=) Linear Isotopic dielectric : Substance for which this assumption is true are called linear isotopic dielectric [LID]

Assumption : The induce dipole moment is in the direction of field & it is proportional field strength.

$$\boxed{P = \epsilon_0 \chi_e E}$$

χ_e = dielectric constant.

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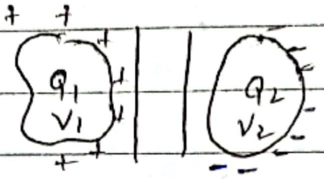
capacitor is a device ... the form of electric field

* Capacitor and Capacitance

It is the ability of capacitor to store charge

=) A capacitor is a system of two conductor separated by an insulator.

=) The conductor have charge q_1 and q_2 & potential v_1 and v_2



* Law of capacitor

=) Potential difference b/w two terminal each proportional to charge.

$$V \propto Q$$

$$Q \propto V$$

$$\boxed{Q = CV}$$

C = constant [capacitance]

It doesn't depends on Q or V

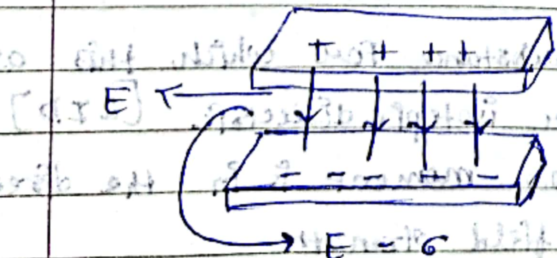
It only depends on shape, size of the capacitor.

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

Capacitance [C] = Farade

D.F. = $[A^2 M^{-1} L^{-2}]$

* The parallel plate capacitor.



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

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

$E = \frac{\sigma}{2\epsilon_0} - \left(-\frac{\sigma}{2\epsilon_0}\right)$

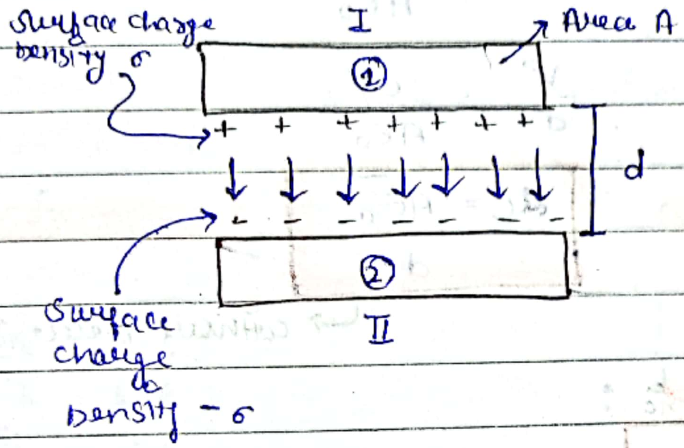
$= \frac{\sigma}{2\epsilon_0} + \frac{\sigma}{2\epsilon_0}$

$= \frac{\cancel{2}\sigma}{\cancel{2}\epsilon_0} = \frac{\sigma}{\epsilon_0}$

Q/A

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

* **Derive the expression of capacitance for parallel plate capacitor separated with distance 'd'**



Electric field inside the parallel plates

$$E = \frac{\sigma}{2\epsilon_0} - \left(\frac{-\sigma}{2\epsilon_0}\right)$$

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

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

We know that, $\sigma = \frac{Q}{A}$

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

Acc. to law of capacitor

$$Q = CV$$

$$E = \frac{CV}{A\epsilon_0} \quad \text{--- (1)}$$

We also know,

$$E = -\frac{dV}{dr}$$

$$E = \frac{V}{d}$$

Put $E = \frac{V}{d}$ in eq (1)

$$E = \frac{CV}{A\epsilon_0}$$

$$\frac{V}{d} = \frac{CV}{A\epsilon_0}$$

$$\boxed{C = \frac{A\epsilon_0}{d}}$$ A = Area.

→ without Dielectric

with Dielectric :

$$\boxed{C = \frac{KA\epsilon_0}{d}}$$

If, $K = \frac{\epsilon_m}{\epsilon_0}$

$$C = \frac{\epsilon_m}{\cancel{\epsilon_0}} \cdot \frac{A\cancel{\epsilon_0}}{d}$$

$$\boxed{C = \frac{\epsilon_m \cdot A}{d}}$$

For potential without Dielectric.

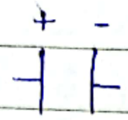
$$V = E \cdot d$$

$$\boxed{V = \frac{Qd}{\epsilon_0 \cdot A}}$$

$$\boxed{K = \frac{C}{C_0}}$$

* Combination of capacitor

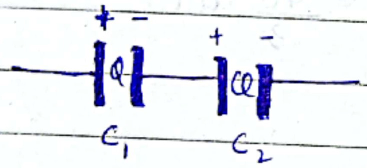
⇒ The effective capacitance depends on the way the individual capacitors are combined.



Symbol of capacitor.

* Capacitors in series

⇒



⇒ charge constant

$$Q_1 = Q_2 = Q$$

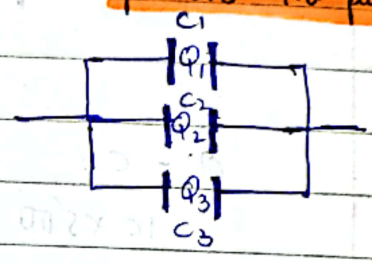
⇒ Potential Difference is variable

$$V_{eq} = V_1 + V_2$$

⇒ $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$

Capacitors in parallel

⇒



⇒ charge is variable

$$Q_{eq} = Q_1 + Q_2 + Q_3$$

⇒ Potential Difference constant

$$V_1 = V_2 = V_3 = V$$

⇒ $C_{eq} = C_1 + C_2 + C_3$

Note: For series

$$\boxed{C_{eq} = \frac{C_1 \cdot C_2}{C_1 + C_2}}$$

$$C_1 = C_2$$

$$C_{eq} = \frac{C\cancel{C}}{2\cancel{C}} = \frac{C}{2}$$

$$\boxed{C_{eq} = \frac{C_1 \cdot C_2 \cdot C_3}{C_1 \cdot C_2 + C_2 \cdot C_3 + C_3 C_1}}$$

$C_1 = C_2 = C_3 \ldots C_n$

$$\boxed{C_{eq} = \frac{C}{n}}$$

eg: $C_{eq} = \frac{\cancel{5}\mu F}{5\cancel{0}_{10}}$

$C_{eq} = 0.1 \mu F$

Electrostatic shielding

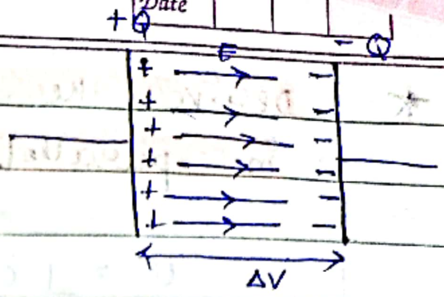
Making a space in conductor free from electric field is k/a electrostatic shielding.

Application of electrostatic shielding.

Electric field is zero inside the hollow space / cavity.

Thunderstorm → If the electricity from the cloud strike on the metal, the person inside the cavity is safe.

In various instrument metallic shield is used to protect the sensitive device from electric field.



* Energy Stored by a capacitor

We know that

$$V = \frac{dW}{dQ}$$

$$dW = V.dQ$$

$$dW = \frac{Q}{C}\,dQ \qquad \boxed{\begin{aligned} Q &= CV \\ V &= Q/C \end{aligned}}$$

$$dW = \frac{1}{C}\int Q\,dQ$$

$$W = \frac{1}{C} \times \frac{Q^2}{2}$$

$$W = \frac{1}{2} \cdot \frac{1}{C} \times (VC)^2$$

$$W = U = \frac{1}{2} \times \frac{1}{\cancel{C}}\, C^{\cancel{2}} \times V^2$$

$$\boxed{U = \frac{1}{2} CV^2}$$

$$U = \frac{1}{2} \times (CV) \times V$$

$$\boxed{U = \frac{1}{2} Q.V}$$

↳ In the form of charge

For parallel plate capacitor

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

For E & ε_0

$$\boxed{U = \frac{1}{2}\varepsilon_0 E^2}$$

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* Derive the expression of energy store per unit volu[me] in parallel plate capacitor.

$$U = \frac{1}{2} C V^2$$

$$U = \frac{1}{2}\left(\frac{A\epsilon_0}{d}\right) \times E^2 d^2 \qquad \left[E = \frac{V}{d}\right]$$

$$U = \frac{1}{2} \frac{A\epsilon_0}{\cancel{d}} \times E^2 d^{\cancel{2}}$$

$$U = \frac{1}{2} \epsilon_0 . E^2 \times (A.d)$$

$$U = \frac{1}{2} \epsilon_0 E^2 \times (\text{volume})$$

$$\boxed{U = \left(\frac{U}{V}\right) = \frac{1}{2}\epsilon_0 E^2}$$

2.10 (a) $Q = CV$

$= 900 \times 10^{-12} \times 100$

$= 9 \times 10^{-8} C$

$$U = \frac{1}{2} C V^2$$

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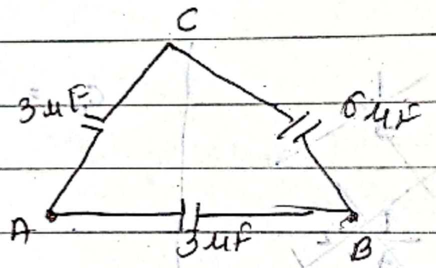
* **Network solving method**

Step-I Identify two points across which equivalent capacitance is to be calculated.

II Connect [imagine] battery b/w this point.

III Solve the network from the point [reference point] which is farthest from the point b/w which we have to calculate equivalent capacitance.

Q

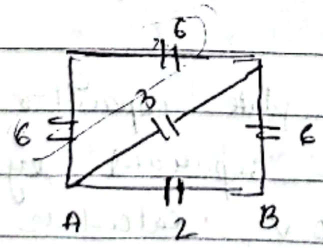


$C_{AB} = \frac{3\times 6}{3+6} + 3 = 2+3 = 5\,\mu F$

$C_{BC} = \frac{3\times 3}{3+3} = \frac{\cancel{9}^{3}}{\cancel{6}_{2}} + \frac{6}{1} = \frac{3+12}{2} = \frac{15}{2}\,\mu F$

$C_{CA} = \frac{6\times 3}{6+3} + 3 = 2+3 = 5\,\mu F$

Q



$C_{AB} = ?$

$\frac{6\times 6}{6+6} = \frac{\cancel{36}^{3}}{\cancel{12}_{1}} = 3+3 = \cancel{6\mu F} = \frac{6\times 6}{6+6} = \frac{\cancel{36}^{3}}{\cancel{12}}$

$= 3+2 = 5\,\mu F$

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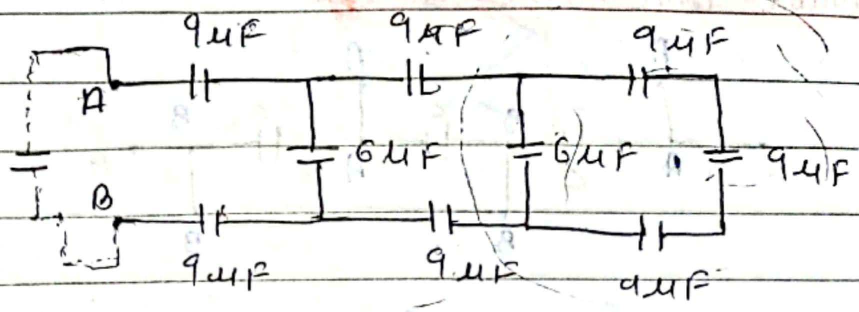


81
81
+81
243

81
×9
729

$$\frac{9\times9\times9}{9\times9+9\times9+9\times9} = \frac{729}{243} = 3\,\mu F$$

$3+6 = 9\,\mu F$

81
×6
486

$$\cancel{\frac{9\times6\times9}{9\times6+6\times9+9\times9} = \frac{486}{54+54+81}} \quad \cancel{\frac{486}{189}}$$

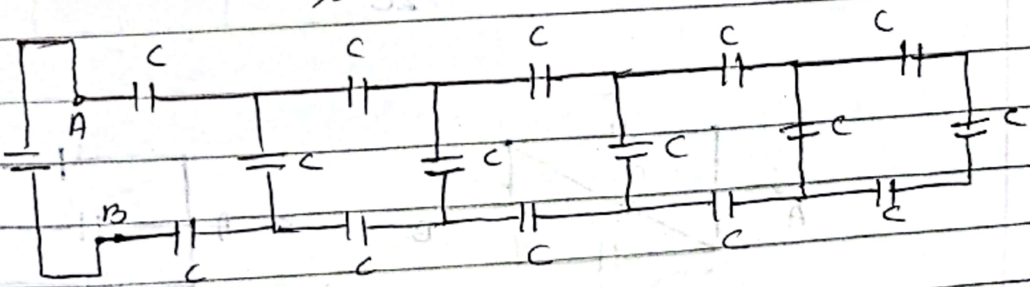
2·7 6

$C_s = \frac{C}{n} = \frac{9}{3} = 3$

$3+6 = 9.$

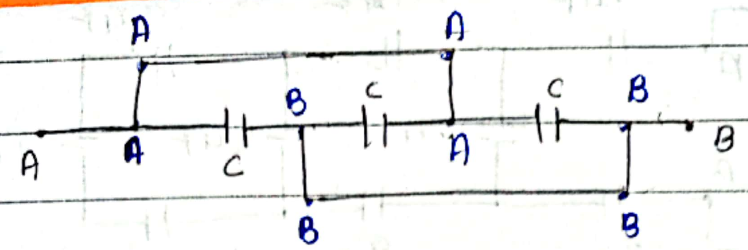
$C_{eq} = \frac{9}{3} = 3\,\mu F = C_{AB}$

4.10

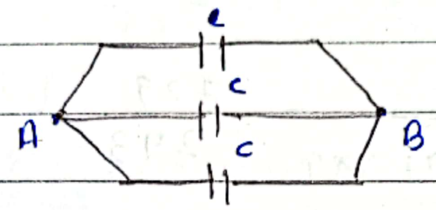


* Circuit with extra wire :

(i)

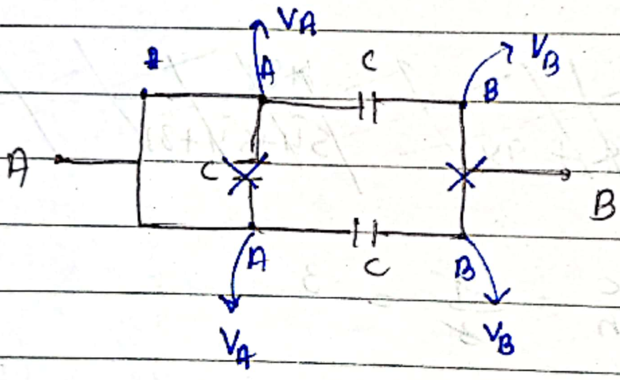


$\Rightarrow$

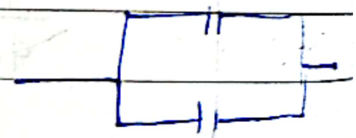


$$\Rightarrow \quad C_{AB} = C + C + C = 3C$$

(ii)



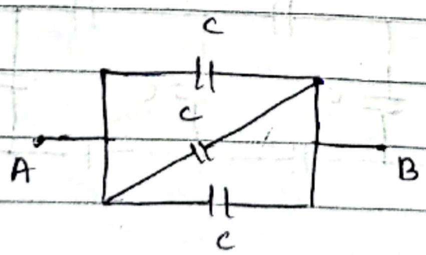
$\Rightarrow$



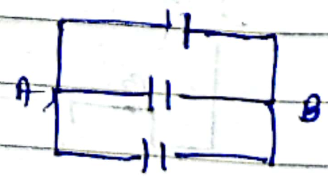
In vertical Branch Potential Difference $= 0$

$$\therefore \quad C_{eq} = C + C$$
$$= 2C$$

(iii)



$\Rightarrow$



$$C_{eq} = 3C$$

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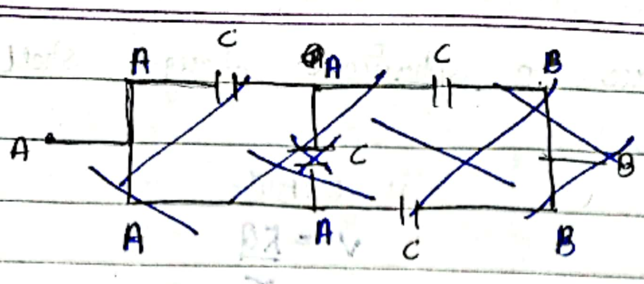
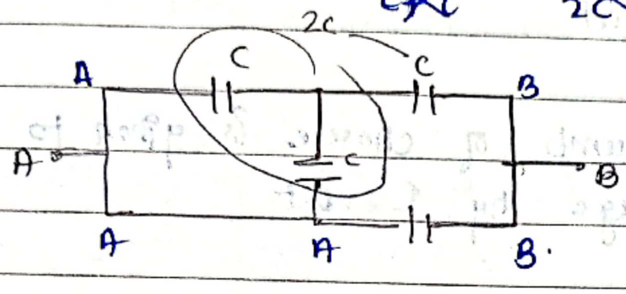


$$C_{eq} = \cancel{\frac{C\times C}{C+C}} = \frac{C^2}{2C} + \frac{C}{1} \quad \cancel{\frac{C^2+2C^2}{2C}}$$

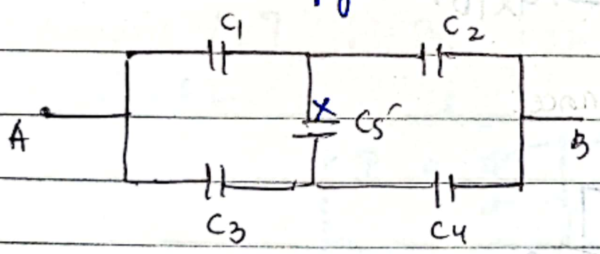
(iii)

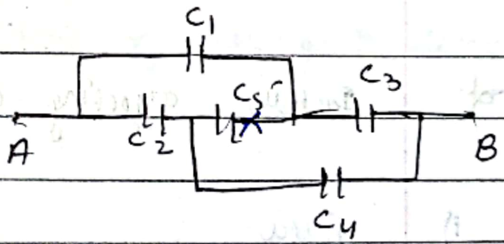


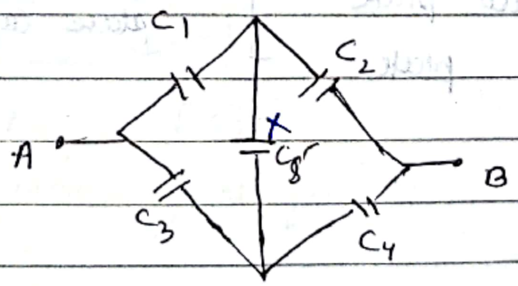
$$\frac{2C\times C}{2C+C} = \frac{2C^{\cancel{2}}}{3\cancel{C}} = \frac{2C}{3} + C = \frac{5C}{3}\ \text{Ans}$$

* Wheatstone Bridge Circuit:

→ If in a network five capacitors are arrange as shown in figures.







Note:

$$\left(\frac{C_1}{C_3} = \frac{C_2}{C_4}\right) \text{ or } \left(\frac{C_1}{C_2} = \frac{C_3}{C_4}\right)$$

$$C_{AB} = \frac{C_1\times C_2}{C_1+C_2} + \frac{C_3\times C_4}{C_3+C_4}$$

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* Potential Due to spherical charged shell.

(i) inside

$V = \frac{KQ}{R}$

(ii) outside

$V = \frac{KQ}{r}$

(iii) surface.

$V = \frac{KQ}{R}$.

Q Define 1 Farad.

→ when 1 coloumb of charge is given to capacitor to rai[se] the voltage by 1 volt

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

↳ unit = Farad.

* Capacitance of spherical Isolated capacitor.

$\boxed{C = \frac{r}{\underbrace{k}_{9\times10^9}}}$ or $\boxed{4\pi\epsilon_0 r = C}$

* Factors affecting capacitance.

1) Area
2) Distance b/w plate
3) Medium b/w plate

For parallel plate capacitor