# UNIT - 1 - Electrostatics

## Exercise problems.

(1.) $q = 50nC$

$= 50 \times 10^{-9} C$

$n = ?$

$q = ne$

$n = \frac{q}{e} = \frac{50 \times 10^{-9}}{1.6 \times 10^{-19}}$

$n = 31.25 \times 10^{10}$ electrons

(2) No. of electrons in the human body $= 10^{28}$

loss of electrons $= 1\%$

No. of electrons in the human body after 1% loss $\left.\right\} = 1\% \times 10^{28}$

$= \frac{1}{100} \times 10^{28}$

$n = 10^{26}$ electrons

$q = ne$

$= 10^{26} \times 1.6 \times 10^{-19}$

$\boxed{q = 1.6 \times 10^{7}}$

$F = \frac{1}{4\pi\varepsilon_0} \times \frac{q_1 q_2}{r^2}$ $\left[ q_1 = q_2 = 1.6 \times 10^{+7} C \quad r = 1m \right]$

$= \frac{9 \times 10^{9} \times 1.6 \times 10^{+7} \times 1.6 \times 10^{7}}{1^2}$

$= 9 \times 2.56 \times 10^{23}$

$\boxed{F = 23.04 \times 10^{23} N}$

Mass of the man $= 60 kg$

weight $= 60 \times 9.8$ $[w = mg]$

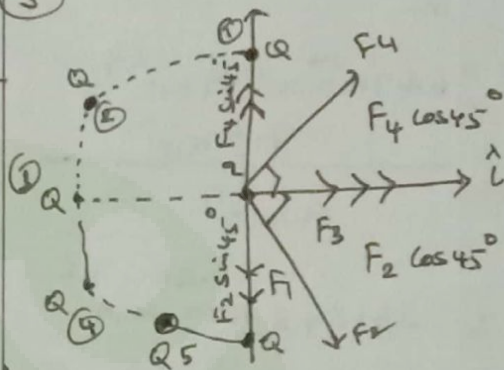
$\boxed{W = 588 N}$

$\frac{F}{W} = \frac{23.04 \times 10^{23}}{588}$

$= 0.03918 \times 10^{23}$

$\boxed{F/W = 3.918 \times 10^{21}}$

(3)




$F_1 = F_5$

$F_2 \sin 45^\circ = F_4 \sin 45^\circ$ (equal & opposite so it cancel each other)

$F_{total} = F_3 + F_2 \cos 45^\circ + F_4 \cos 45^\circ$

$= \frac{kqQ}{R^2} + \frac{kqQ}{R^2}\frac{1}{\sqrt{2}} + \frac{kqQ}{R^2}\frac{1}{\sqrt{2}}$

$= \frac{kqQ}{R^2} + \frac{2kqQ}{\sqrt{2}R^2}$

$= \frac{kqQ}{R^2} + \frac{\sqrt{2}kqQ}{R^2}$

$\boxed{\vec{F}_{total} = \frac{kQq}{R^2}\left[1 + \sqrt{2}\right] N \hat{i}}$

$\hat{i} \rightarrow$ Force acting along x axis

(4) For balance the gravitational force of attraction between Earth and moon.

a)

$$F_e = F_g$$

$$\frac{K q q}{r^2} = \frac{G M_E M_M}{\cancel{r^2}}$$

$$q^2 = \frac{G}{K} M_E M_M$$

$$= \frac{6.67\times10^{-11} \times 5.9\times10^{24} \times 7.9\times10^{22}}{9\times10^{9}}$$

$$q^2 = 34.543 \times 10^{-20} \times 10^{46}$$

$$q^2 = 34.543 \times 10^{26}$$

$$q = \sqrt{34.543\times10^{26}}$$

$$\boxed{q = 5.877\times10^{13}\, C}$$

b) $r = r/2$

$$\frac{K (q)(q)}{(\cancel{r/2})^2} = \frac{G M_E M_M}{(\cancel{r/2})^2}$$

$$K(q^2) = G M_E M_M$$

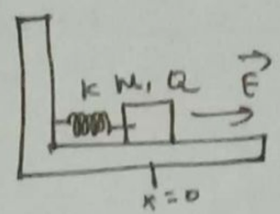
$$q^2 = \frac{G M_E M_M}{K}$$

$$\boxed{q = 5.877\times10^{13}\, C}$$

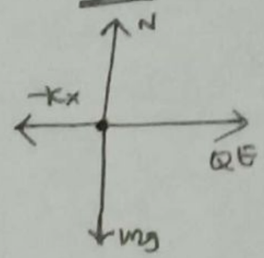
If the distance between the Earth and Moon is halved the Charge will remain Same

(5)

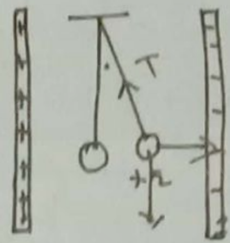
a)

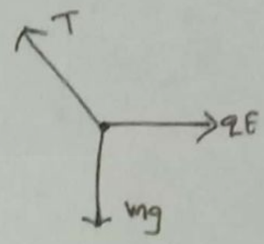



Ans

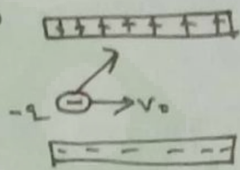



b)



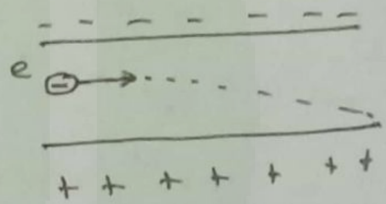



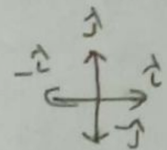

c)





(6)




$$F = ma$$

$$F = eE$$

$$eE = ma$$

$$\boxed{a = \frac{eE}{m}}$$

$$\boxed{\vec{a} = \frac{eE}{m}(-\hat{j}) = -\frac{eE}{m}\hat{j}}$$

$$\vec{v} = \vec{u} + \vec{a}t$$

$$\boxed{\vec{v} = v_0\hat{i} - \frac{eE}{m}t(\hat{j})}$$

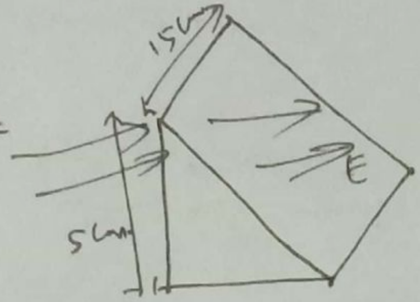
$$S = ut + \frac{1}{2}at^2$$

$$\vec{r} = \vec{u}t + \frac{1}{2}\vec{a}t^2$$

$$\boxed{\vec{r} = v_0\hat{i}t - \frac{1}{2}\frac{eE}{m}t^2\hat{j}}$$

7

$E = 2\times10^{3}\,N/C$




$\int ds = s = l \times b$

$= 15\times10^{-2} \times 5\times10^{-2}$

$\int ds = s = 75\times10^{-4}\, m^2$

a) vertical rectangular surface

Here $\theta = 0°$

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

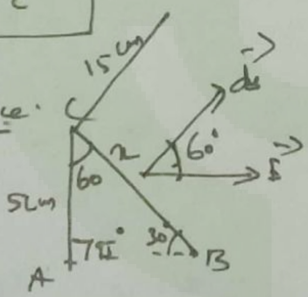
$= \oint E\, ds$

$= E \oint ds$

$= 2\times10^{3} \times 75\times10^{-4}$

$\boxed{\phi = 15\ N m^2 C^{-1}}$

b) slanted surface.




$\theta = 60°$

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

$= 2\times10^{3} \times 150\times10^{-4} \times \frac{1}{2}$

$= 150\times10^{-1}$

$\boxed{\phi = 15\, N m^2 C^{-1}}$

$\Delta ABC$

$\sin 30° = \frac{5\times10^{-2}}{x}$

$x = \frac{5\times10^{-2}}{\sin 30°}$

$= \frac{5\times10^{-2}}{1/2}$

$\boxed{x = 10\times10^{-2}\, m}$

$\int ds = s = l \times x$

$= 10\times10^{-2} \times 15\times10^{-2}$

$= 150\times10^{-4}$

c) entire surface:

$\phi = 0$ (closed surface net charge is zero)

in vertical field lines are entering into the surface, in slanted surface same amount of field lines are going outward from the surface.

Net flux $= -15 + 15$

$\boxed{\phi = 0}$

$\because$ entering into the surface $= -15$

getting out from the surface $= +15$

8 refer figure in the question.

i) region A

$E = -\frac{dv}{dx}$

$= -\frac{(8-5)}{(0.2-0)} = -\frac{3}{0.2}$

$\boxed{E = -(-15) = 15\ Vm^{-1}}$

ii) region B

There is no change in the potential with respect to x

so $dv = 0$

$\boxed{E = 0}$

iii) region C

$E = -\frac{dv}{dx}$

$= -\frac{(7-5)}{(0.6-0.4)} = -\frac{2}{0.2}$

$\boxed{E = -10\ Vm^{-1}}$

iv) region D:

$$E = -\frac{dv}{dx}$$

$$= -\frac{(7-1)}{(0.8-0.6)}$$

$$= -\frac{6}{0.2} = -30$$

$$\boxed{E = -(-30) = 30\,Vm^{-1}}$$

9) $d = 0.6\,mm = 0.6\times10^{-3}\,m$

$E = 3\times10^{6}\,Vm^{-1}$

a) $V = E\times d$

$$= 3\times10^{6}\times0.6\times10^{-3}$$

$$= 3\times6\times10^{6}\times10^{-4}$$

$$\boxed{V = 18\times10^{2} = 1800\,V}$$

b) If the gap between the electrodes is increased, (at constant electric field → E) the potential also increases

$V \propto d$ (E is constant)

c) $d = 1\,mm = 1\times10^{-3}\,m$

$V = Ed = 3\times10^{6}\times1\times10^{-3}$

$= 3\times10^{3}$

$\boxed{V = 3000\,V}$

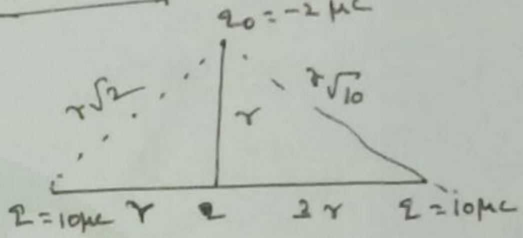
10) Initial Position.

$r = 5\,cm$ $3r = 15\,cm$

$q = 10\,\mu C$ $q_0 = -2\,\mu C$ $q = 10\,\mu C$

$$\boxed{U_i = -\frac{Kqq_0}{r} - \frac{Kqq_0}{3r} + \frac{Kq^2}{4r}}$$

Final Position:




$$U_f = -\frac{Kqq_0}{r\sqrt{2}} - \frac{Kqq_0}{r\sqrt{10}} + \frac{Kq^2}{4r}$$

$$W = U_f - U_i = -\frac{Kqq_0}{r\sqrt{2}} - \frac{Kqq_0}{r\sqrt{10}} + \cancel{\frac{Kq^2}{4r}} + \frac{Kqq_0}{r} + \frac{Kqq_0}{3r} - \cancel{\frac{Kq^2}{4r}}$$

$$= \frac{Kqq_0}{r}\left[-\frac{1}{\sqrt{2}} - \frac{1}{\sqrt{10}} + \frac{1}{1} + \frac{1}{3}\right]$$

$$= \frac{Kqq_0}{r}\left[\frac{4}{3} - \left(\frac{\sqrt{2}+\sqrt{10}}{\sqrt{20}}\right)\right]$$

$$= \frac{9\times10^{9}\times2\times10^{-6}\times10\times10^{-6}}{5\times10^{-2}}\left[\frac{4}{3} - \frac{4.576}{4.472}\right]$$

$$= \frac{9\times\overset{4}{\cancel{20}}\times10^{-3}}{\cancel{5}\times10^{-2}}\left[1.333 - 1.023\right]$$

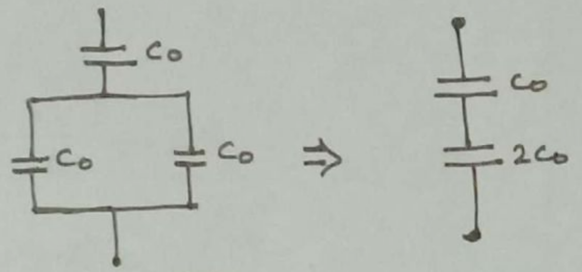
$$= 36\times10^{-1}\left[0.31\right]$$

$$= 3.6\times0.31$$

$$\boxed{W = 1.116\,J}$$

To separate the negative charge from to positive charge work is done on the system

11 a)



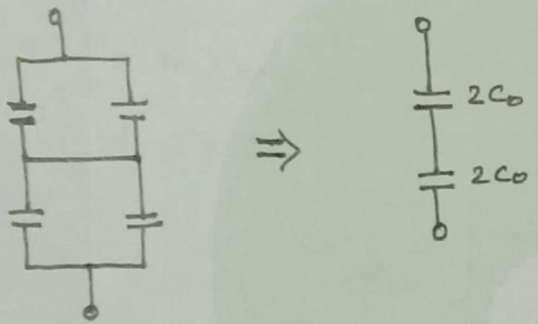

$C_p = C_0 + C_0 = 2C_0$

$\frac{1}{C_s} = \frac{1}{C_0} + \frac{1}{2C_0} = \frac{2C_0 + C_0}{2C_0^2}$

$\frac{1}{C_s} = \frac{3C_0}{2C_0^2}$

$\boxed{C_s = \frac{2C_0^2}{3C_0} = \frac{2}{3} C_0}$

b)

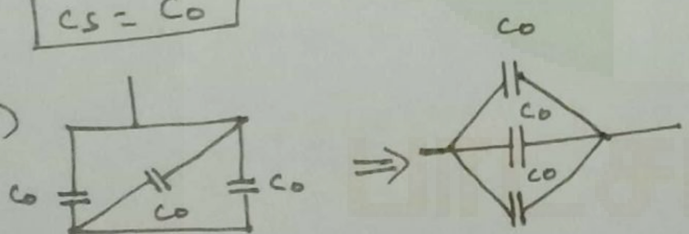



$\boxed{C_p = C_0 + C_0 = 2C_0}$

$\frac{1}{C_s} = \frac{1}{2C_0} + \frac{1}{2C_0} = \frac{4C_0}{4C_0^2} = \frac{1}{C_0}$

$\boxed{C_s = C_0}$

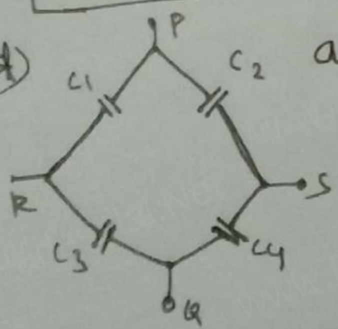
c)




$C_p = C_1 + C_2 + C_3 = C_0 + C_0 + C_0$

$\boxed{C_p = 3C_0}$

d)




across PQ:

$C_1$ and $C_2$ are in series

$\frac{1}{C_{s_1}} = \frac{1}{C_1} + \frac{1}{C_2}$

$\boxed{C_{s_1} = \frac{C_1 C_2}{C_1 + C_2}}$

$C_3$ and $C_4$ are in series

$\frac{1}{C_{s_2}} = \frac{1}{C_3} + \frac{1}{C_4}$

$\boxed{C_{s_2} = \frac{C_3 C_4}{C_3 + C_4}}$

$C_{s_1}$ and $C_{s_2}$ are in parallel

$C_p = C_{s_1} + C_{s_2}$

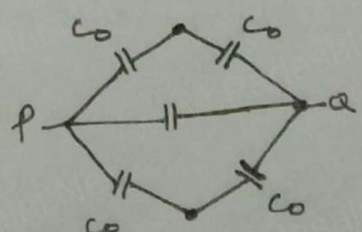
$= \frac{C_1 C_2}{C_1 + C_2} + \frac{C_3 C_4}{C_3 + C_4}$

$= \frac{C_1 C_2 (C_3 + C_4) + C_3 C_4 (C_1 + C_2)}{(C_1 + C_2)(C_3 + C_4)}$

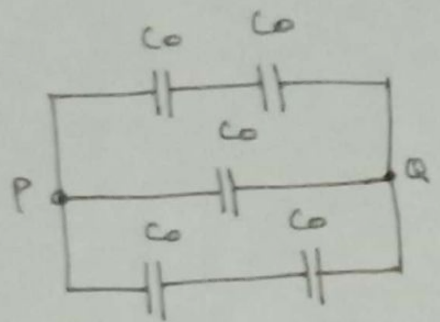
$\boxed{C_p = \frac{C_1 C_2 C_3 + C_1 C_2 C_4 + C_1 C_3 C_4 + C_2 C_3 C_4}{(C_1 + C_2)\, C_3 + C_4}}$

If we find across RS also same as across PQ.

e)

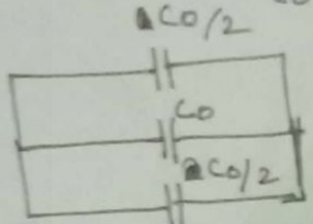


equivalent circuit




$$\frac{1}{C_{S_1}} = \frac{1}{C_0} + \frac{1}{C_0} = \frac{2}{C_0} \Rightarrow$$

$$\frac{1}{C_{S_2}} = \frac{1}{C_0} + \frac{1}{C_0} = \frac{2}{C_0}$$



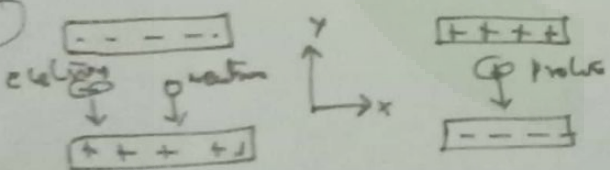

$$C_p = C_{S_1} + C_{S_2} + C_0$$

$$= \frac{C_0}{2} + \frac{C_0}{2} + C_0$$

$$= \frac{2C_0}{2} + C_0$$

$$\boxed{C_p = 2C_0}$$

(12)




$V = 5V$;

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

$m_p = 1.6 \times 10^{-27} kg$

$g = 10 m s^{-2}$

$s = h = d = 1 \times 10^{-3} m.$

a) Time of flight for electron and proton

for electron:

$S = ut + \frac{1}{2}at^2 \qquad u = 0$

$s = \frac{1}{2}at^2$

$$t^2 = \frac{2s}{a}$$

$$a = F/m = \frac{Ee}{m} = \frac{Ve}{dm} \quad \left[\because E = \frac{V}{d}\right]$$

$$t_e = \sqrt{\frac{2s}{a}} = \sqrt{\frac{2 \cdot s \cdot d \cdot m_e}{V \cdot e}}$$

$$= \sqrt{\frac{2 \times 10^{-3} \times 10^{-3} \times 9.1 \times 10^{-31}}{5 \times 1.6 \times 10^{-19}}}$$

$$= \sqrt{\frac{18.2 \times 10^{-37}}{8 \times 10^{-19}}}$$

$$= \sqrt{2.275 \times 10^{-37} \times 10^{+19}}$$

$$= \sqrt{2.275 \times 10^{-18}}$$

$$= 1.5 \times 10^{-9} s$$

$$\boxed{t_e = 1.5 ns}$$

Proton

$$t_p = \sqrt{\frac{2 \times s \times d \times m_p}{V \cdot e}}$$

$$= \sqrt{\frac{2 \times 10^{-3} \times 10^{-3} \times 1.67 \times 10^{-27}}{5 \times 1.6 \times 10^{-19}}}$$

$$= \sqrt{\frac{3.34 \times 10^{-33}}{8 \times 10^{-19}}}$$

$$= \sqrt{0.4175 \times 10^{-14}}$$

$$= \sqrt{\cancel{8.64}}$$

$$= 0.646 \times 10^{-7}$$

$$= 64.6 \times 10^{-9} s$$

$$\boxed{t_p = 64 ns}$$

b) Neutron has no charge. So it does not experience any electrostatic force, So it will experience only gravitational ~~[illegible]~~ Pull.

$s = ut + \frac{1}{2}at^2 \qquad u = 0$

$s = \frac{1}{2}gt^2$

$t^2 = \frac{25}{9}$

$t = \sqrt{\frac{25}{9}} = \sqrt{\frac{2\times10^{-3}}{10}}$

$= \sqrt{0.2\times10^{-3}}$

$= \sqrt{2\times10^{-4}}$

$\boxed{t_n = 1.414\times10^{-2}\ s}$

d) $t_e = 1.5\ ns$

$t_p = 64\ ns$

$t_n = 1.414\times10^{-2}s$

$\boxed{t_n = 14.14\ ms}$

So the time of flight for electron is very less. So the electron will reach the bottom quickly when comparing with other two (proton & neutron)

(13) $E = 3\times10^6\ Vm^{-1}$ ; $d = 1000m$.

a) ~~[illegible]~~ $E = V/d$

~~[illegible]~~ $V = E.d$

$= 3\times10^6\times1000$

$\boxed{V = 3\times10^9\ V}$

b) $q = 25C$

$U = ?$

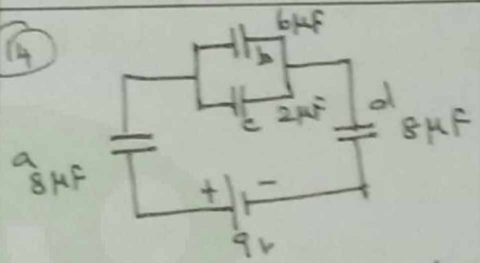
The work done is stored as electrostatic potential energy

$W = U = V.q$

$= 3\times10^9\times25$

$\boxed{U = 75\times10^9\ J}$

(14)



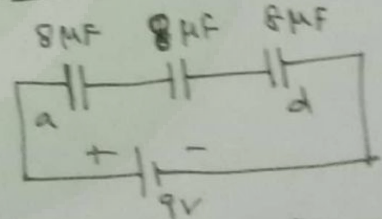

b & c capacitors are in parallel combination so,

$c_p = c_b + c_c$

$= 6+2$

$\boxed{c_p = 8\mu F}$

Simplified diagram




In above diagram the capacitors are in series

$\frac{1}{c_s} = \frac{1}{8} + \frac{1}{8} + \frac{1}{8} = \frac{3}{8}$

$\boxed{c_s = \frac{8}{3}\mu F}$

a) Charges on each capacitor

Total charge on the capacitor on $C_s$

$q = C_s V$

$= \frac{8}{3}\times10^{-6}\times9$

$\boxed{q = 24\mu C}$

In Series combination the charge on each capacitor is Same.

So: $q_a = 24\mu C$

$q_d = 24\mu C$

$q_{b\&c} = 24\mu C$

In given diagram.

$q_b$ and $q_c$ are different.

(because b & c capacitor are not in series, it is in parallel combination: So the charges across b & c are different)

charge on b

[to find charge on b & c the voltage across a, b&c, d are 3 volt (∵ 9v = 3+3+3)]

$q_b = C_b \times V_b$

$= 6\times10^{-6} \times 3$

$\boxed{q_b = 18\mu C}$

charge on c.

$q_c = C_c \times V_c$

$= 2\times10^{-6} \times 3$

$= 6\times10^{-6}$

$\boxed{q_c = 6\mu C}$

b) Potential difference across them

$V_a = \frac{q_a}{C_a} = \frac{24\times10^{-6}}{8\times10^{-6}} = 3V$

$V_b = \frac{q_b}{C_b} = \frac{18\times10^{-6}}{6\times10^{-6}} = 3V$

$V_c = \frac{q_c}{C_c} = \frac{6\times10^{-6}}{2\times10^{-6}} = 3V$

$V_d = \frac{q_d}{C_d} = \frac{24\times10^{-6}}{8\times10^{-6}} = 3V$

c) Energy stored in each capacitor

across a

$U_a = \frac{1}{2} C_a V_a^2$

$= \frac{1}{2} \times 8\times10^{-6} \times (3)^2$

$\boxed{U_a = 36\times10^{-6} J}$

across (b)

$U_b = \frac{1}{2} C_b V_b^2$

$= \frac{1}{2} \times 6\times10^{-6} \times (3)^2$

$\boxed{U_b = 27\times10^{-6} J}$

across (c)

$U_c = \frac{1}{2} C_c V_c^2$

$= \frac{1}{2} \times 2\times10^{-6} \times (3)^2$

$\boxed{U_c = 9\times10^{-6} J}$

across (d)

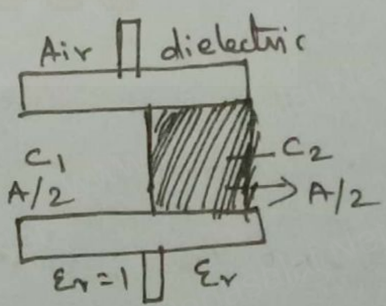
$U_d = \frac{1}{2} C_d V_d^2$

$= \frac{1}{2} \times 8\times10^{-6} \times (3)^2$

$\boxed{U_d = 36\times10^{-6} J}$

15

i)




$\varepsilon_r = 1$ for air medium

In the above diagram $C_1$ and are in parallel combination.

$$C_1 = \frac{\varepsilon_0 A/2}{d}$$

$$\boxed{C_1 = \frac{\varepsilon_0 A}{2d}}$$

$$C_2 = \frac{\varepsilon A/2}{d}$$

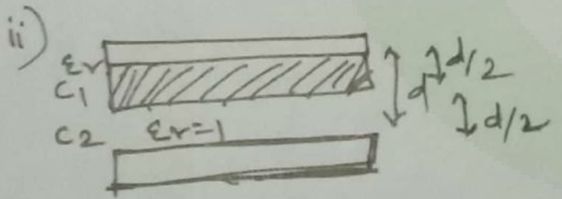
$$\boxed{C_2 = \frac{\varepsilon_0 \varepsilon_r A}{2d}}$$

$$C_p = C_1 + C_2$$

$$= \frac{\varepsilon_0 A}{2d} + \frac{\varepsilon_0 \varepsilon_r A}{2d}$$

$$\boxed{C_p = \frac{\varepsilon_0 A}{2d}\left[1 + \varepsilon_r\right]}$$

ii)




$$C_1 = \frac{\varepsilon_0 \varepsilon_r A}{d/2} \quad \text{[in medium]}$$

$$\boxed{C_1 = \frac{2\varepsilon_0 \varepsilon_r A}{d}}$$

$$C_2 = \frac{\varepsilon_0 A}{d/2} \quad \text{[in Air]}$$

$$\boxed{C_2 = \frac{2\varepsilon_0 A}{d}}$$

$C_1$ and $C_2$ are in series combination

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$= \frac{1}{\frac{2\varepsilon_0 \varepsilon_r A}{d}} + \frac{1}{\frac{2\varepsilon_0 A}{d}}$$

$$= \frac{d}{2\varepsilon_0 \varepsilon_r A} + \frac{d}{2\varepsilon_0 A}$$

$$\frac{1}{C_s} = \frac{d}{2\varepsilon_0 A}\left[\frac{1}{\varepsilon_r} + 1\right]$$

$$\frac{1}{C_s} = \frac{d}{2\varepsilon_0 A}\left[\frac{\varepsilon_r + 1}{\varepsilon_r}\right]$$

$$\boxed{C_s = \frac{2\varepsilon_0 A}{d}\left[\frac{\varepsilon_r}{\varepsilon_r + 1}\right]}$$