* Example 1.1 (Not in new syllabus)

We can charge the sphere by following steps -

(I) Take an uncharged metallic sphere on an insulating stand. Fig (a)

(II) Bring a -ve charged rod close to the sphere.

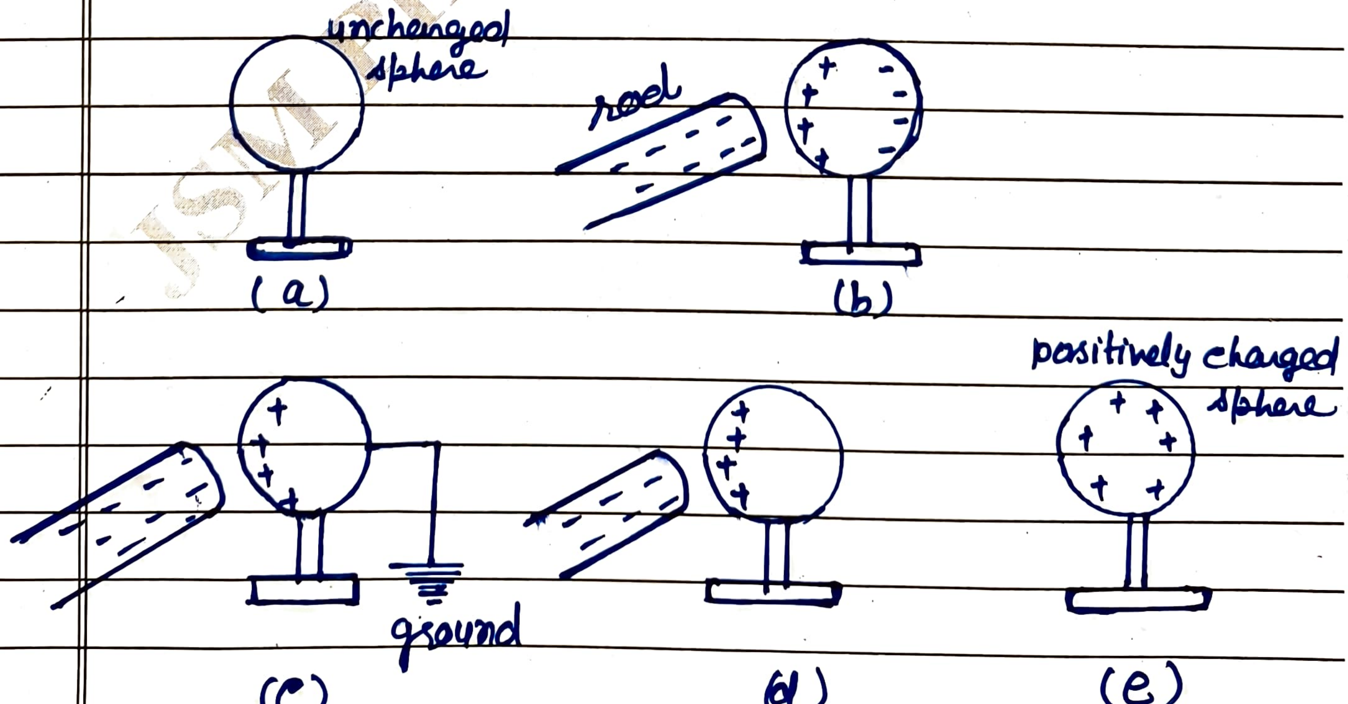
(III) Due to the repulsion free electrons in the sphere collect to the farther end. Fig (b)

(IV) Connect the sphere to the ground by a conducting wire as shown in fig (c).

(V) Electrons flow to the ground while protons remain held due to the attraction of the rod. Fig (d)

(VI) Disconnect the sphere from the ground and remove the electrified rod.

(VII) The +ve charge spreads uniformly over the sphere. Fig (e)



Example 1.2

Given,

Number of electrons move in 1 sec = 10^9

Total charge = 1 c

Number of electrons in 1 c of charge is given by

$$n = \frac{q}{e} \qquad [\because q = ne]$$

$$= \frac{1}{1.6 \times 10^{-19}} = 6.25 \times 10^{18}$$

Given that

10^9 electrons take time to move = 1 sec

so. 6.25×10^{18} electrons will take time to move

$$= \frac{1}{10^9} \times 6.25 \times 10^{18} \text{ sec}$$

$$= 6.25 \times 10^9 \text{ sec}$$

Hence the time required to get a charge of 1 c on the other body is 6.25×10^9 sec. or 198 years. Ans

[$\because$ 1 year = 31536000 sec

$\therefore$ 6.25×10^9 sec $= \frac{6.25 \times 10^9}{31536000}$ years

= 198 years]

Example 1.3

Let the mass of 1 cup water = 250 g.

We know molecular mass of water (H_2O) = 18 g

i.e number of molecules in 18 g = 1 mole

$= 6.023 \times 10^{23}$

so number of molecules in 250g $= \frac{6.023 \times 10^{23}}{18} \times 250$

$= \frac{250}{18} \times 6.023 \times 10^{23}$

We know H_2O contains 2 hydrogen atoms and 1 oxygen atom. i.e total (2+1) = 3 atoms

i.e 10 electrons and 10 protons (+10e and −10e)

Hence total +ve charge = total −ve charge.

which is given by

$$q = \frac{250}{18} \times 6.023 \times 10^{23} \times 10e$$

$$= \frac{250}{18} \times 6.023 \times 10^{23} \times 10 \times 1.6 \times 10^{-19}$$

$[\because e = 1.6 \times 10^{-19} C]$

$$= 1.33 \times 10^{7} C$$

Ans

Example 1.4

(a) Comparision of electrostatic force and gravitational force -

(i) For an electron and a proton

$$\frac{F_e}{F_G} = \frac{\frac{1}{4\pi\epsilon_0}\cdot\frac{q_e q_p}{r^2}}{\frac{G m_e m_p}{r^2}} = \frac{\frac{1}{4\pi\epsilon_0} e^2}{G m_e m_p}$$

$$= \frac{9\times10^{9}\times(1.6\times10^{-19})^2}{6.67\times10^{-11}\times 9.11\times10^{-31}\times1.67\times10^{-27}}$$

$$= \frac{9\times1.6\times1.6\times10^{9-38+11+31+27}}{6.67\times9.11\times1.67}$$

or

$$\frac{F_e}{F_G} = 2.4\times10^{39}$$

or $F_e = 2.4\times10^{39} F_G$

* $(F_G << F_e)$

(ii) For two protons

$$\frac{F_e}{F_G} = \frac{\frac{1}{4\pi\epsilon_0} e^2}{G m_p^2} = \frac{9\times10^{9}\times(1.6\times10^{-19})^2}{6.67\times10^{-11}\times(1.67\times10^{-27})^2}$$

or $$\frac{F_e}{F_G} = \frac{9\times1.6\times1.6\times10^{9-38+11+54}}{6.67\times1.67\times1.67}$$

$$\frac{F_e}{F_G} = 1.3\times10^{36}$$

i.e $F_e = 1.3\times10^{36} F_G$

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Acceleration of proton

$$a_p = \frac{ke^2/r^2}{m_p}$$

$$= \frac{9\times10^9 \times (1.6\times10^{-19})^2}{(10^{-10})^2 \times 1.67\times10^{-27}}$$

$$= \frac{9\times1.6\times1.6}{1.67} \times 10^{9-38+20+27}$$

$$a_p = 1.44\times10^{19}\ m/s^2$$

Ans.

Example 1.5

Initially

$q_A = q_1 \qquad q_B = q_2$

$r_1 = r = 10\ cm = 10\times10^{-2}\ m$

$$F = k\frac{q_A q_B}{r^2}$$

$$F = k\frac{q_1 q_2}{r^2} \quad -(1)$$

After redistribution of charges

$q_A = \frac{q_1}{2}, \quad q_B = \frac{q_2}{2}$

$r_2 = \frac{r}{2}$

Now $F' = k\frac{\frac{q_1}{2}\cdot\frac{q_2}{2}}{(r/2)^2} = k\frac{q_1 q_2}{r^2} = F$ [from (1)]

$\boxed{F' = F}$ Forces remains unchanged Ans.

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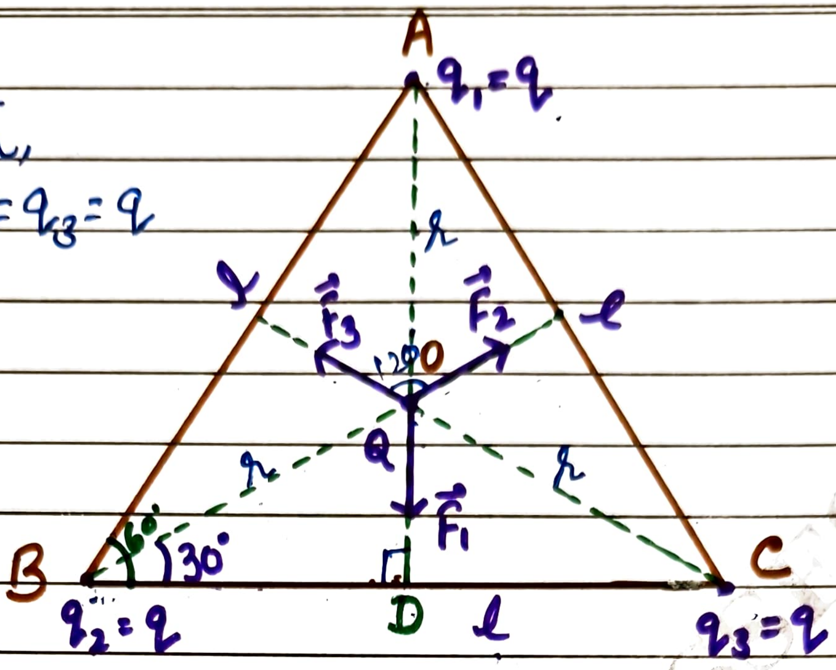
Example 1.6

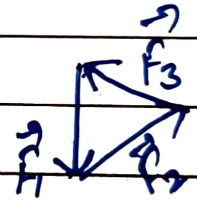
Given,

$q_1 = q_2 = q_3 = q$



I Method - Here $|\vec{F_1}| = |\vec{F_2}| = |\vec{F_3}|$ and $\vec{F_1}, \vec{F_2}$ and $\vec{F_3}$ vectors form a closed polygon. Therefore

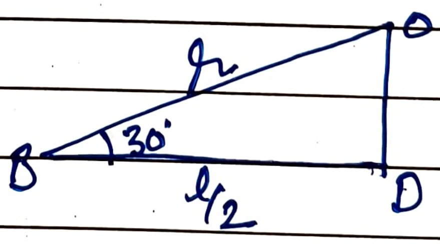
$$\vec{F}_{net} = \vec{F_1} + \vec{F_2} + \vec{F_3}$$
$$= 0$$



II Method -

By symmetry $OA = OB = OC = r$

$$\cos 30^\circ = \frac{l/2}{r}$$



$$\frac{\sqrt{3}}{2} = \frac{l}{2r}$$

$$\Rightarrow \boxed{r = \frac{l}{\sqrt{3}}}$$

$$F_1 = \frac{k.qQ}{(l/\sqrt{3})^2} \qquad \left[\because r = \frac{l}{\sqrt{3}}\right]$$

$$F_1 = \frac{3kqQ}{l^2} \quad [\text{along } AO]$$

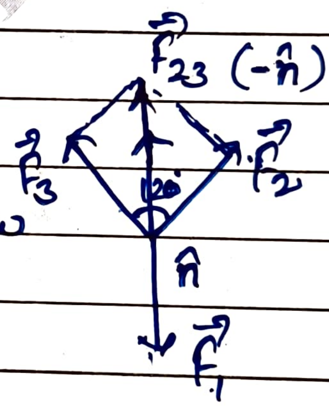
$$F_2 = \frac{3kqQ}{l^2} \quad [\text{along } BO]$$

and

$$F_3 = \frac{3k.qQ}{l^2} \quad [\text{along } CO]$$

Resultant of $\vec{F}_2$ and $\vec{F}_3$

By using parallelograms law



$$|\vec{F}_{23}| = |\vec{F}_2| = |\vec{F}_3|$$

$$= \frac{3kqQ}{l^2}$$

from fig

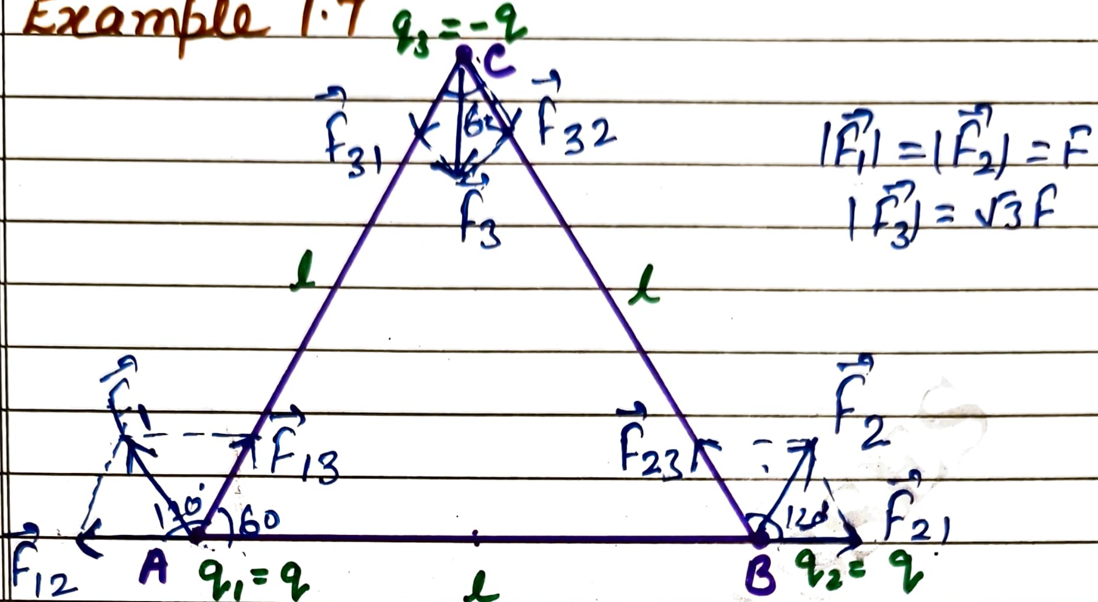
$$\vec{F}_1 + \vec{F}_{23} = 0 \qquad [|\vec{F}_{23}| = |\vec{F}_1|]$$

or

$$\vec{F}_1 + \vec{F}_2 + \vec{F}_3 = 0$$

$$\vec{F}_{net} = 0$$

Example 1.7



At point 'A'

$$\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13}$$

here

$|\vec{F}_{12}| = |\vec{F}_{13}|$ and $\theta = 120°$

So,

$$|\vec{F}_1| = |\vec{F}_{12}| = |\vec{F}_{13}| = \frac{kq^2}{l^2} = F$$

and the direction of $\vec{F}_1$ is along BC.

At point 'B'

$$\vec{F}_2 = \vec{F}_{21} + \vec{F}_{23}$$

here $|\vec{F}_{23}| = |\vec{F}_{21}|$ and $\theta = 120°$

therefore,

$$|\vec{F}_2| = |\vec{F}_{21}| = |\vec{F}_{23}| = \frac{kq^2}{l^2} = F$$

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and direction of $\vec{F_2}$ is along AC

Now at point 'C'

$\vec{F_3} = \vec{F_{31}} + \vec{F_{32}}$ and $\theta = 60^\circ$

$|\vec{F_{31}}| = \frac{Kq^2}{l^2}$, $|\vec{F_{32}}| = \frac{Kq^2}{l^2} = F$

$|\vec{F_{31}}| = |\vec{F_{32}}| = F$

$F_3 = \sqrt{F_{31}^2 + F_{32}^2 + 2F_{31} \cdot F_{32} \cos 60^\circ}$

$= \sqrt{F^2 + F^2 + \cancel{2} F \cdot F \times \frac{1}{\cancel{2}}}$

$= \sqrt{2F^2 + F^2}$

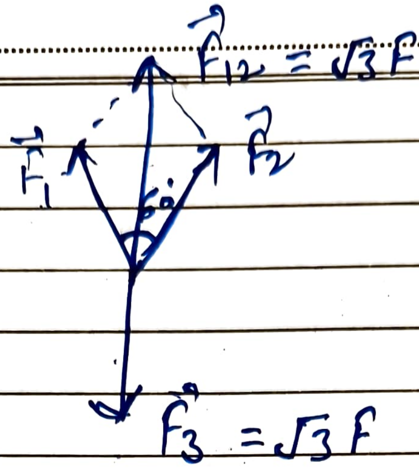
$F_3 = \sqrt{3F^2}$

$F_3 = \sqrt{3} F$

$|\vec{F_3}| = \sqrt{3} F$

$F_1 = F_2 = F$, $F_3 = \sqrt{3} F$

direction of $\vec{F_3}$ is along bisector of $\angle C$



$\vec{F}_1 + \vec{F}_2 + \vec{F}_3 = 0$

$F_{12} = \sqrt{F_1^2 + F_2^2 + 2F_1F_2 \cos 60}$

$= \sqrt{F^2 + F^2 + 2F^2 \cdot \frac{1}{2}}$

$F_{12} = \sqrt{3F^2} = \sqrt{3}F$

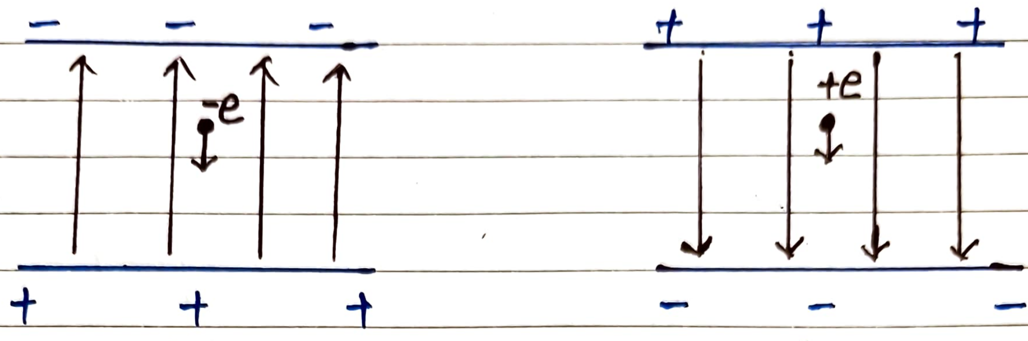
$\vec{F}_{12}$ and $\vec{F}_3$ are opposite and equal

So.

$\vec{F}_{12} + \vec{F}_3 = 0$

$\vec{F}_1 + \vec{F}_2 + \vec{F}_3 = 0$

Example 1.8



(a) (b)

Given,

Distance $S = 1.5 \text{ cm} = 1.5 \times 10^{-2} m$

Electric field $E = 2 \times 10^{4} NC^{-1}$

We know

$e = 1.6 \times 10^{-19} C$

$m_e = 9.11 \times 10^{-31} kg$

$m_p = 1.67 \times 10^{-27} kg$

and $t = ?$

For Fig. (a)

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

here $u = 0$

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

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

$$t = \sqrt{\frac{2S}{a}}$$

or $$t = \sqrt{\frac{2h}{a}}$$

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$$t_e = \sqrt{\frac{2S}{a_e}}$$

$$t_e = \sqrt{\frac{2S}{F/m_e}} \qquad [\because F = ma]$$

$$t_e = \sqrt{\frac{2S \times m_e}{eE}} \qquad [\because F = qE = eE]$$

$$= \sqrt{\frac{2 \times 1.5 \times 10^{-2} \times 9.1 \times 10^{-31}}{1.6 \times 10^{-19} \times 2 \times 10^{4}}}$$

$$= \sqrt{\frac{1.5 \times 9.1}{1.6} \times 10^{-2-31+19-4}}$$

$$= \sqrt{\frac{13.65 \times 10^{-18}}{1.6}}$$

$$= \sqrt{8.53 \times 10^{-18}}$$

$$t_e = 2.9 \times 10^{-9} \text{ sec}$$

Ans

$$\begin{array}{r|l} & 2.9 \\ 2 & \overline{8.53} \\ & 4 \\ \hline 49 & 453 \\ & 441 \end{array}$$

For fig.(b)

$$t_p = \sqrt{\frac{2S \times m_p}{eE}}$$

$$= \sqrt{\frac{2 \times 1.5 \times 10^{-2} \times 1.67 \times 10^{-27}}{1.6 \times 10^{-19} \times 2 \times 10^{4}}}$$

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$$t_p = \sqrt{\frac{1.5 \times 1.67}{1.6} \times 10^{-2-27+19-4}}$$

$$= \sqrt{\frac{2.505}{1.6} \times 10^{-14}}$$

$$= \sqrt{1.56 \times 10^{-14}}$$

$$t_p = 1.25 \times 10^{-7} \text{ sec} \quad \text{Ans}$$

$$a_e = \frac{eE}{m_e} = \frac{1.6 \times 10^{-19} \times 2 \times 10^{4}}{9.1 \times 10^{-31}}$$

$$a_e = 2 \times 1.75 \times 10^{15} \text{ m/s}^2$$

$$\underline{a_e = 3.5 \times 10^{15} \text{ m/s}^2}$$

also

$$a_p = \frac{eE}{m_p} = \frac{1.6 \times 10^{-19} \times 2 \times 10^{4}}{1.67 \times 10^{-27}}$$

$$\underline{a_p = 1.9 \times 10^{12} \text{ m/s}^2}$$

we have $g = 9.8 \text{ m/s}^2$

so. a_e and $a_p >>> g$

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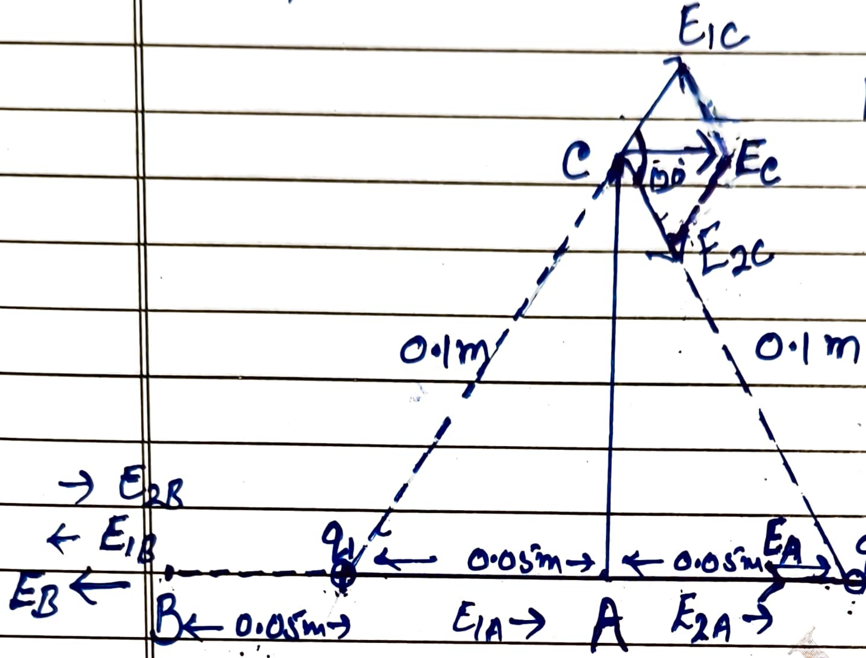
Example 1.9



$|\vec{E}_{1C}| = |\vec{E}_{2C}| = |\vec{E}_C|$

$q_1 = 10^{-8} C$

$q_2 = -10^{-8} C$

Electric field at point 'A' –

Electric field due to charge q_1

$$E_{1A} = \frac{kq}{r^2} = \frac{9\times10^9\times10^{-8}}{(0.05)^2} \quad \text{[towards right]}$$

$$E_{1A} = \frac{9\times10}{25\times10^{-4}}$$

$$E_{1A} = 3.6\times10^4 \, N/C$$

Now

$$E_{2A} = \frac{9\times10^9\times10^{-8}}{(0.05)^2} = 3.6\times10^4 \, N/C$$

$$E_{2A} = 3.6\times10^4 \, N/C \quad \text{[towards right]}$$

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Net field at 'A'

$E_A = E_{1A} + E_{2A}$

$= 3.6 \times 10^4 + 3.6 \times 10^4$

$E_A = 7.2 \times 10^4$ N/C

Direction is towards right.

Electric field at point 'B'

$E_{1B} = \frac{9 \times 10^9 \times 10^{-8}}{(0.05)^2}$

$E_{1B} = 3.6 \times 10^4$ N/C [towards left]

Now $E_{2B} = \frac{9 \times 10^9 \times 10^{-8}}{(0.05 + 0.1)^2} = \frac{9 \times 10}{(0.15)^2}$

$= \frac{9 \times 10}{225 \times 10^{-4}}$

$E_{2B} = 0.4 \times 10^{+4}$ N/C [towards right]

Net field at 'B'

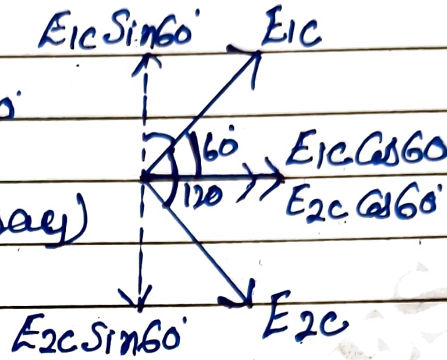
$E_B = E_{1B} + E_{2B}$

$= 3.6 \times 10^4 - 0.4 \times 10^4$

$E_B = 3.2 \times 10^4$ N/C

Direction of E_B is towards left.

Electric field at point 'C'



$E_C = E_{1C} \cos 60° + E_{2C} \cos 60°$

Here $|\vec{E}_{1C}| = |\vec{E}_{2C}| = E$ (say)

$E_C = 2E \cos 60°$

$= 2E \times \frac{1}{2}$

$E_C = E = \frac{kq}{r^2} = \frac{9 \times 10^9 \times 10^{-8}}{(0.1)^2}$

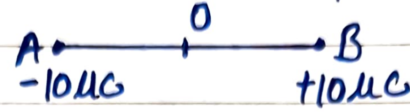
$= \frac{9 \times 10^{1}}{0.01}$

$E_C = 9 \times 10^3$ N/C

Direction is towards right.

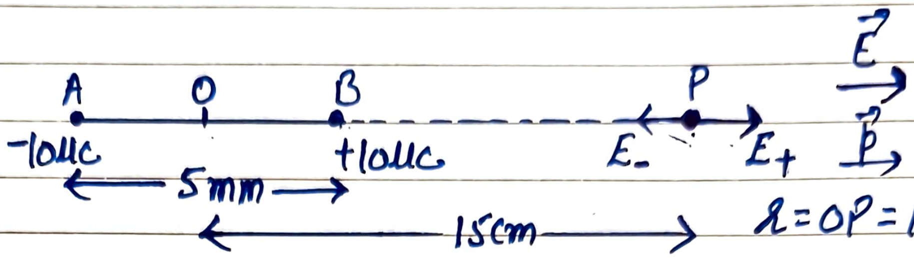
Example 1.10

Here AB is an electric dipole of length 5 mm.



$AB = 2a = 5\,mm$

(a)



$r = OP = 15\,cm$
$= 15 \times 10^{-2}\,m$

$$E_{axial} = E_p = \frac{k(2p)\cdot r}{(r^2 - a^2)^2}$$

here $r = 15\,cm$ and $a = 2.5\,mm$

$a << r$ therefore we neglect a.

and we get

$$E_p = \frac{k(2p)}{r^3} = \frac{k \times 2 \times 2aq}{r^3}$$

$$= \frac{9 \times 10^9 \times 2 \times 5 \times 10^{-3} \times 10 \times 10^{-6}}{(15 \times 10^{-2})^3}$$

$$= \frac{90 \times 10^9 \times 10^{-9} \times 10}{15 \times 15 \times 15 \times 10^{-6}}$$

$$= \frac{900 \times 10^6}{15 \times 15 \times 15}$$

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or $E_P = \frac{\overset{4}{\cancel{60}}\cancel{900} \times 10^6}{\cancel{15}\times\cancel{15}\times 15}$

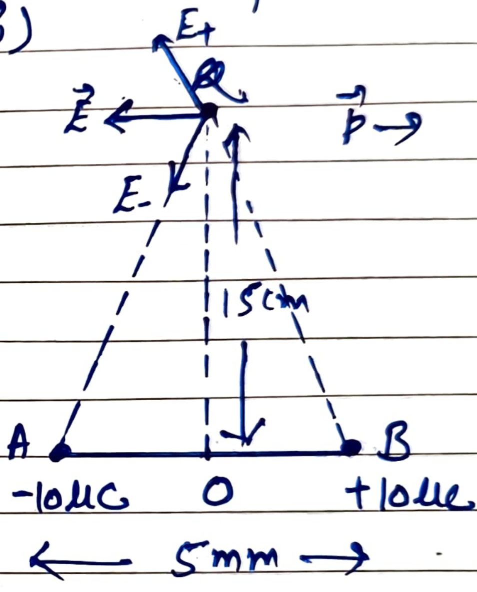
$= \frac{4\times 10^6}{15}$

$= \frac{40}{15}\times 10^5 = \frac{8}{3}\times 10^5$

$E_P = 2.67\times 10^5$ N/C

Direction of electric field at point P is along BP. (Along $\vec{p}$)

(b)



$E_{equatorial} = \frac{E_{axial}}{2} = \frac{E_P}{2}$

$E_Q = \frac{2.67\times 10^5}{2}$

$E_Q = 1.33\times 10^5$ N/C

Direction of electric field at point Q is along BA. (opposite to $\vec{p}$)

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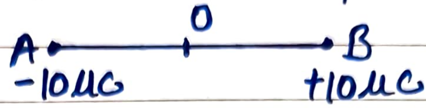
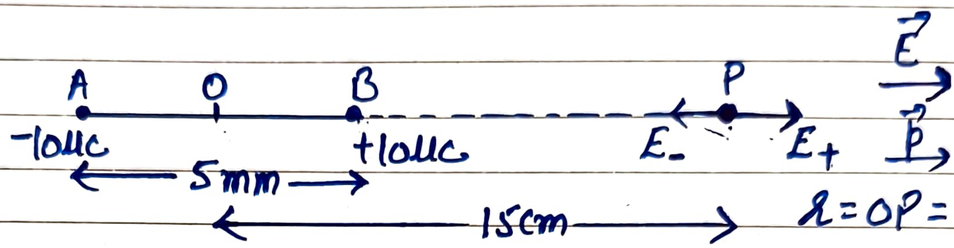
Example 1.10

Here AB is an electric dipole of length 5mm.



$AB = 2a = 5\,mm$

(a)



$r = OP = 15\,cm$

$= 15 \times 10^{-2}\,m$

$$E_{axial} = E_p = \frac{k(2p)\cdot r}{(r^2-a^2)^2}$$

here $r = 15\,cm$ and $a = 2.5\,mm$

$a << r$ therefore we neglect a.

and we get

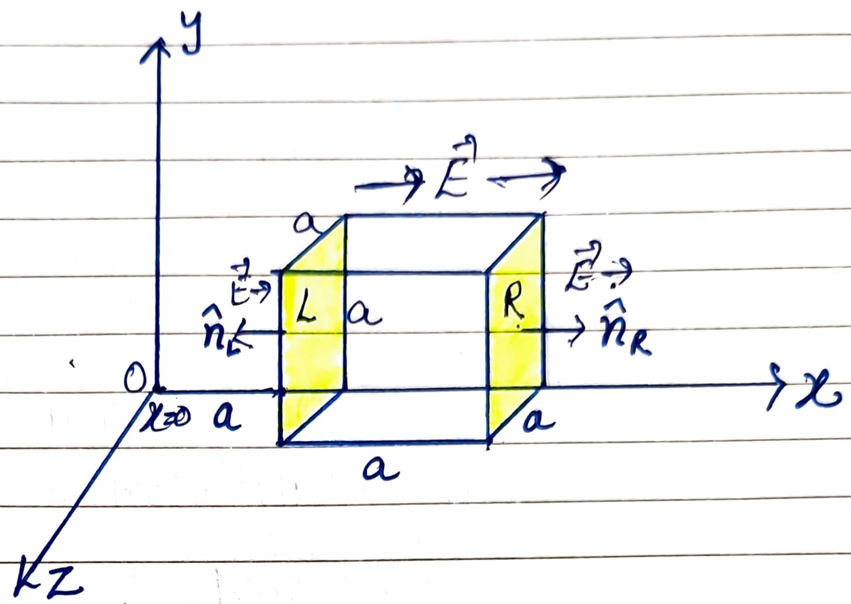
$$E_p = \frac{k(2p)}{r^3} = \frac{k \times 2 \times 2aq}{r^3}$$

$$= \frac{9\times10^9 \times 2 \times 5\times10^{-3} \times 10\times10^{-6}}{(15\times10^{-2})^3}$$

$$= \frac{90\times10^9 \times 10^{-9} \times 10}{15\times15\times15\times10^{-6}}$$

$$= \frac{900 \times 10^6}{15\times15\times15}$$

Example 1.11



$E_x = \alpha x^{1/2}$, $E_y = E_z = 0$, $a = 0.1 m$

$\alpha = 800 \; N/C\,m^{1/2}$

(a) Flux through the cube

$$\phi = \phi_L + \phi_R$$

$$\phi_L = \vec{E_L} \cdot \vec{S} = E_L S \cos\theta$$

$$= \alpha x^{1/2} (a^2) \cos 180^\circ$$

$$= \alpha a^{1/2} \cdot a^2 (-1) \qquad [x = a, S = a^2]$$

$$\phi_L = -\alpha a^{5/2} \; Nm^2/C$$

Now

$$\phi_R = \vec{E_R} \cdot \vec{S} = E_R S \cos\theta$$

$$= \alpha x^{1/2} a^2 \cos 0^\circ$$

$$= \alpha (2a)^{1/2} a^2 (1)$$

$$\phi_R = \sqrt{2} \alpha a^{5/2} \; N m^2/C$$

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$\phi = \phi_L + \phi_R$

$= -\alpha a^{5/2} + \sqrt{2}\alpha a^{5/2}$

$= \alpha a^{5/2}[\sqrt{2}-1]$

$= \alpha a^{5/2}[1.414-1]$

$= \alpha a^{5/2} \times 0.414$

$= 800 \times (0.1)^{5/2} \times 0.414$

$= 331.2 \times (0.1)^{1/2} (0.1)^2$

$= \frac{331.2}{\sqrt{10}} \times 0.01$

$= \frac{3.312}{3.16}$

$= 1.048$

$\phi_{net} = 1.05 \ Nm^2/C$

Ans

$$\begin{array}{r|l} & 3.16 \\ 3 & 10 \\ & 9 \\ \hline 61 & 100 \\ & 61 \\ \hline 626 & 3900 \end{array}$$

(b) By Gauss's law

$\phi = \frac{q_{enclosed}}{\epsilon_0}$

or $q_{en} = \epsilon_0 \phi$

$= 8.854 \times 10^{-12} \times 1.05$

$q_{en} = 9.29 \times 10^{-12} \ C$ Ans

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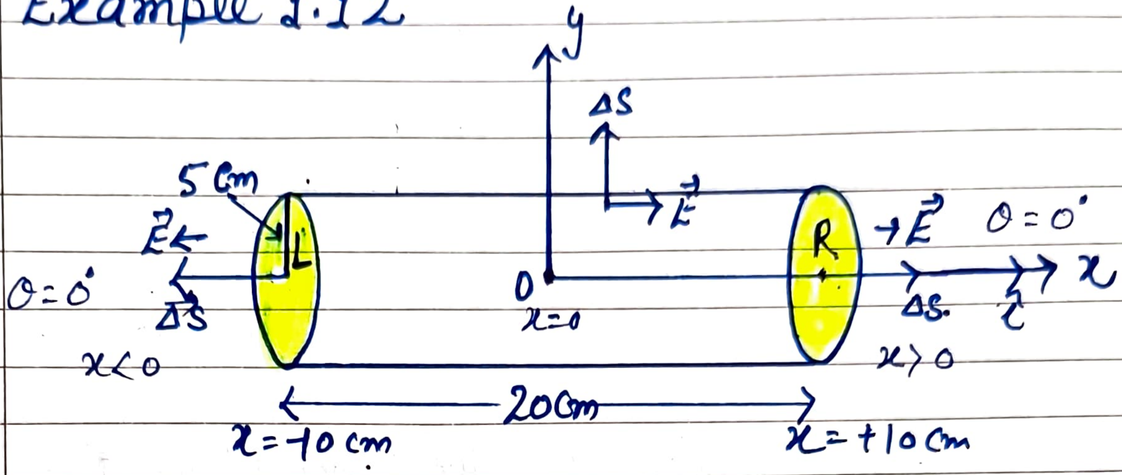
Example 1.12



$E = 200\hat{i}$ N/C $\quad [x > 0]$

$E = -200\hat{i}$ N/C $\quad [x < 0]$

(a) $\phi_L = \vec{E}\cdot\vec{\Delta S} = E\Delta S\cos\theta$

$= 200 \times (\pi \times r^2)\cos\theta$

$= 200\pi \times (5\times10^{-2})^2 \cos 0°$

$= 200\pi \times 25 \times 10^{-4}$ $\quad [\cos 0° = 1]$

$= 5000\pi \times 10^{-4}$

$\phi_L = 0.5\pi$ N m²/C

and $\phi_R = \vec{E}\cdot\vec{\Delta S} = E\Delta S\cos\theta$

$= 200 \times (\pi r^2)\cos\theta$

$= 200\pi (5\times10^{-2})^2 \cos 0°$

$\phi_R = 0.5\pi$ N m²/C

i.e. $\phi_L = \phi_R$ Ans

$= 0.5\pi = 0.5 \times 3.14 = \underline{1.57\ \text{N m}^2/\text{C}}$

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(b) $\phi_c = \vec{E} \cdot \vec{\Delta S}$

$= E \Delta S \cos\theta$

here $\theta = 90^\circ$ $[\because E \perp \Delta S]$

$\phi_c = 0$ $[\cos 90^\circ = 0]$

(c) Net outward flux through the cylinder

$\phi_{net} = \phi_L + \phi_R + \phi_c$

$= 0.5\pi + 0.5\pi + 0$

$= 1.0\pi$

$\phi_{net} = 3.14 \ Nm^2/C$

(d) Charge inside the cylinder

By Gauss's law

$q_{en} = \epsilon_0 \phi$

$= 8.854 \times 10^{-12} \times 3.14$

$q = 2.78 \times 10^{-11} C$

Ans

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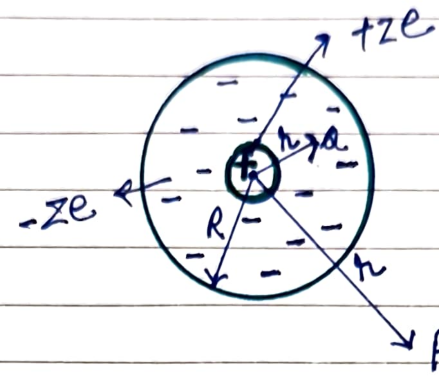
Example 1.13



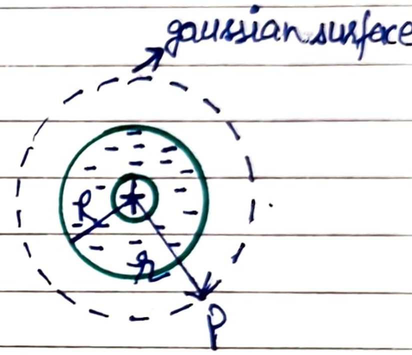
Z = No. of electron/proton

e = charge of electron

r → Distance from nucleus

R → Radius of spherical atom

(i) **Electric field at point 'P': Outside the sphere ($r > R$)**



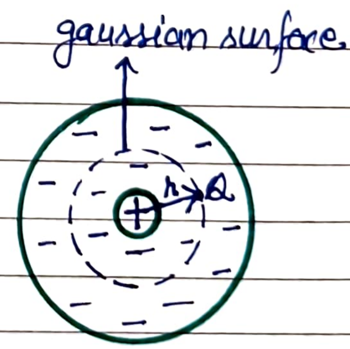
By Gauss law

$$\phi = \vec{E}\cdot\vec{A} = \frac{q_{enclosed}}{\epsilon_0}$$

or $$E \times 4\pi r^2 = \frac{Ze - Ze}{\epsilon_0} = 0$$

or $$E = 0$$

(ii) **Electric field at point 'Q' Inside the sphere ($r < R$)**



$$q_{enclosed} = Ze - \frac{Ze}{\frac{4}{3}\pi R^3} \times \frac{4}{3}\pi r^3$$

$$q_{en} = Ze - Ze\frac{r^3}{R^3}$$

By Gauss law

$$E \times 4\pi r^2 = \frac{q_{en}}{\epsilon_0} = \frac{Ze - Ze\frac{r^3}{R^3}}{\epsilon_0}$$

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or $E \times 4\pi r^2 = \frac{ze}{\epsilon_0}\left[1 - \frac{r^3}{R^3}\right]$

or $E = \frac{1}{4\pi\epsilon_0} \cdot \frac{ze}{r^2}\left[1 - \frac{r^3}{R^3}\right]$

$= \frac{1}{4\pi\epsilon_0} ze \left[\frac{1}{r^2} - \frac{r^3}{r^2 R^3}\right]$

or $E = \frac{1}{4\pi\epsilon_0} \cdot ze\left[\frac{1}{r^2} - \frac{r}{R^3}\right]$

i.e Electric field at point P ($r > R$)

$E_P = 0$

and electric field at point Q ($r < R$)

$E_Q = \frac{ze}{4\pi\epsilon_0}\left[\frac{1}{r^2} - \frac{r}{R^3}\right]$

* $E_{surface} = 0$

Teacher's Sign ....