Pradeeps publication (+2) Physics Vol 1 (Dr. K. L Gomber , K. L. Gogia)

SOLVED EXAMPLES

TYPE I QUANTIZATION OF CHARGE

Formula used. $q = \pm ne$

Units used. q and e are in coulomb, n is a number

Standard value. $e = 1{\cdot}6 \times 10^{-19}$ coulomb

Example 1 **Which is bigger, a coulomb or charge on an electron ? How many electronic charges form one coulomb of charge ?** **(Pb. Board 2011)**

Solution. A coulomb of charge is bigger than the charge on an electron.

Magnitude of charge on one electron,

$e = 1{\cdot}6 \times 10^{-19}$ coulomb

Number of electronic charges in one coulomb,

$$n = \frac{q}{e} = \frac{1}{1{\cdot}6 \times 10^{-19}} = \mathbf{0{\cdot}625 \times 10^{19}}$$

Note that *one coulomb is too big a unit of charge.*

Example 2 **How much positive and negative charge is there in a cup of water ?**

NCERT Solved Example

Solution. Suppose the cup contains 250 cc of water (H_2O).

Mass of 250 cm^3 of water = 250 g.

Molecular weight of water = 2 + 16 = 18

Number of molecules in 18 g of water

$= 6{\cdot}023 \times 10^{23}$

Number of molecules in 250 g of water

$$= \frac{6{\cdot}023 \times 10^{23} \times 250}{18}$$

As each molecule of water contains 10 electrons, therefore, total number of electrons,

$$n = \frac{10 \times 6{\cdot}023 \times 10^{23} \times 250}{18} = 8{\cdot}365 \times 10^{25}$$

As $q = ne$, therefore,

$q = 8{\cdot}365 \times 10^{25} \times 1{\cdot}6 \times 10^{-19}$ C

$= 1{\cdot}338 \times 10^{7}$ C

Solution. Here, $n = 10^9$ electrons/sec

Charge given/sec,

$q = ne = 10^9 \times 1{\cdot}6 \times 10^{-19}$ C

$= 1{\cdot}6 \times 10^{-10}$ C

Total charge, Q = 1 C

$\therefore$ Time required $= \frac{Q}{q} = \frac{1}{1{\cdot}6 \times 10^{-10}}$ sec

$$= 6{\cdot}25 \times 10^9 \text{ s} = \frac{6{\cdot}25 \times 10^9}{3600 \times 24 \times 365} \text{ year}$$

$= \mathbf{198{\cdot}18}$ **year**

Example 4 **Two bodies A and B carry charges – 3·00 μC and – 0·44 μC. How many electrons should be transferred from A to B so that they acquire equal charges?**

Solution. Here, $q_1 = -3{\cdot}00$ μC

and $q_2 = -0{\cdot}44$ μC

Let n electrons be transferred from A to B, when A and B would carry same charge.

$\therefore$ Charge on A = Charge on B

$-3{\cdot}00 + ne = -0{\cdot}44 - ne$

$2ne = 3{\cdot}00 - 0{\cdot}44 = 2{\cdot}56$ (μC)

$$n = \frac{2{\cdot}56}{2e}$$

Taking $e = 1{\cdot}6 \times 10^{-19}$ C $= 1{\cdot}6 \times 10^{-13}$ μC

$$n = \frac{2{\cdot}56}{2 \times 1{\cdot}6 \times 10^{-13}} = 0{\cdot}8 \times 10^{13}$$

$= \mathbf{8 \times 10^{12}}$

TYPE II COULOMB'S LAW

Formulae used. $F_0 = \frac{1}{4\pi\epsilon_0} \frac{|q_1||q_2|}{r^2}$;

$$F_m = \frac{1}{4\pi\epsilon} \frac{|q_1||q_2|}{r^2} = \frac{1}{4\pi\epsilon_0\epsilon_r} \frac{|q_1||q_2|}{r^2}$$

Units used.

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$= \mathbf{1{\cdot}338 \times 10^{7}\ C}$

Example 3 **If a body gives out 10^9 rons every second, how much time is required t a total charge of 1 C from it ?**

NCERT Solved Example

Solution. Here, $n = 10^9$ electrons/sec

Charge given/sec,

$q = ne = 10^9 \times 1{\cdot}6 \times 10^{-19}$ C

$= 1{\cdot}6 \times 10^{-10}$ C

Total charge, Q = 1 C

$$\therefore \text{Time required} = \frac{Q}{q} = \frac{1}{1{\cdot}6 \times 10^{-10}} \text{ sec}$$

$$= 6{\cdot}25 \times 10^9\ s = \frac{6{\cdot}25 \times 10^9}{3600 \times 24 \times 365} \text{ ye}$$

$= \mathbf{198{\cdot}18\ year}$

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Solution. Here, $q_1 = -3{\cdot}00\ \mu C$

and $q_2 = -0{\cdot}44\ \mu C$

Let n electrons be transferred from A to B, v A and B would carry same charge.

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$$n = \frac{2{\cdot}56}{2e}$$

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$$F_m = \frac{1}{4\pi\epsilon} \frac{|q_1||q_2|}{r^2} = \frac{1}{4\pi\epsilon_0\epsilon_r} \frac{|q_1||q_2|}{r^2}$$

Units used. q_1, q_2 are in coulomb, F in newton an r in metre.

Standard Values. $\frac{1}{4\pi\epsilon_0} = 9 \times 10^9\ Nm^2\ C^{-2}$

$\epsilon_0 = 8{\cdot}85 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$

Example 5 **A free pith ball P of 10 g carries a positive charge of 5×10^{-8} C. What must be the nature and magnitude of charge that should be given to another pith ball Q fixed 7 cm below the former ball, so that upper ball is stationary ?**

(Hr. Board 2001)

Solution. Here, $m = 10$ g $= 10 \times 10^{-3}$ kg,
$q_1 = 5 \times 10^{-8}$ C, $r = 7$ cm $= 7 \times 10^{-2}$ m

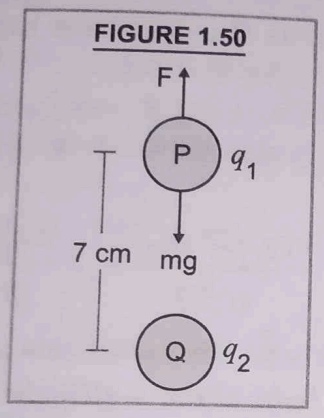
Second ball Q must carry positive charge so that force of repulsion balances the weight of ball P.

When ball remains stationary, Fig. 1.50,

$$F = mg$$

$$\frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2} = mg$$

FIGURE 1.50



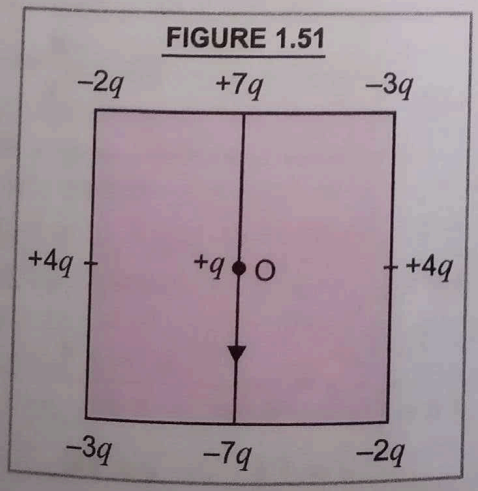
$$\frac{9\times10^9 \times 5\times10^{-8} \times q_2}{(7\times10^{-2})^2} = 10 \times 10^{-3} \times 9{\cdot}8$$

$$q_2 = \frac{10\times10^{-3}\times9{\cdot}8\times(7\times10^{-2})^2}{9\times10^9\times5\times10^{-8}}$$

$$= \mathbf{1{\cdot}067 \times 10^{-6}\ C}$$

Example 6 **A particle carrying charge is held at the centre of a square of each side metre. It is surrounded by eight charges nged on the square as shown in Fig. 1.51. If q C, what is the net force on the particle?**

FIGURE 1.51



Solution. As is clear from Fig. 1.51, forces on the particle at O due to $(-2q, -2q)$; $(-3q, -3q)$ and $(+4q, +4q)$ are equal and opposite. They cancel out in pairs. However, forces due to $+7q$ and $-7q$ add up. Therefore, net force on the particle at O is

$$F = \frac{1}{4\pi\epsilon_0} \times \frac{(7q)(q) + 7q(q)}{(1/2)^2}$$

$$= \frac{9\times10^9 \times 14 (2\times10^{-6})^2}{1/4}$$

$$= 36 \times 14 \times 4 \times 10^{-3}\ \text{N}$$

$$= \mathbf{2{\cdot}016\ N}$$

Example 7 **Coulomb's law for electrostatic force between two point charges and Newton's law for gravitational force between two stationary point masses, both have inverse square dependence on the distance between the charges/ masses (a) compare the strength of these forces by determining the ratio of their magnitudes (i) for an electron and a proton (ii) for two protons (b) estimate the accelerations for electron and proton due to electrical force of their mutual attraction when they are 1 Å apart.**

NCERT Solved Example

Solution. (a) (i) For an electron and proton

$$|F_e| = \frac{1}{4\pi\epsilon_0}\frac{e\times e}{r^2};$$

$$|F_g| = \frac{G m_e . m_p}{r^2}$$

$$\frac{|F_e|}{|F_g|} = \frac{1}{4\pi\epsilon_0}\frac{e^2}{G m_e m_p}$$

$$= \frac{9\times10^9\,(1{\cdot}6\times10^{-19})^2}{6{\cdot}67\times10^{-11}\times9\times10^{-31}\times1{\cdot}66\times10^{-27}}$$

$$= \mathbf{2{\cdot}3 \times 10^{39}}$$

(ii) Similarly, for two protons,

$$\frac{|F_e|}{|F_g|} = \frac{1}{4\pi\epsilon_0}\frac{e^2}{G.m_p m_p}$$

$$= \frac{9\times10^9\,(1{\cdot}6\times10^{-19})^2}{6{\cdot}67\times10^{-11}\times(1{\cdot}66\times10^{-27})^2}$$

$$= \mathbf{1{\cdot}3 \times 10^{36}}$$

(*b*) Force of mutual attraction between an electron and a proton,

$$F = \frac{1}{4\pi\epsilon_0}\frac{e^2}{r^2} = \frac{9\times10^9\,(1{\cdot}6\times10^{-19})^2}{(10^{-10})^2}$$

$$= 2{\cdot}3\times10^{-8}\ \text{N}$$

$$\text{Acceleration of electron} = \frac{F}{m_e} = \frac{2{\cdot}3\times10^{-8}}{9\times10^{-31}}$$

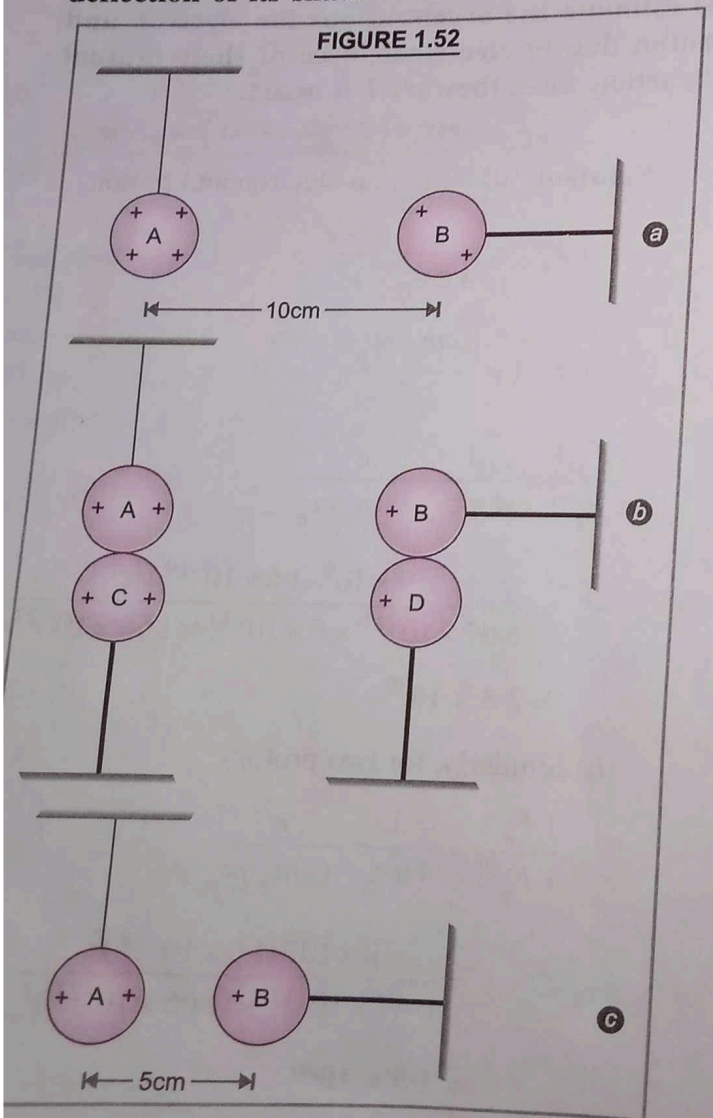
$$= \mathbf{2{\cdot}5\times10^{22}\ m/s^2}$$

$$\text{Acceleration of proton} = \frac{F}{m_p} = \frac{2{\cdot}3\times10^{-8}}{1{\cdot}66\times10^{-27}}$$

$$= \mathbf{1{\cdot}3\times10^{19}\ m/s^2}$$

Example 8 **A charged metallic sphere A is suspended by a nylon thread. Another charged metallic sphere B carried by an insulating handle is brought close to A such that the distance between their centres is 10 cm as shown in Fig. 1.52(*a*). The resulting repulsion of A is noted (for example, by shining a beam of light and measuring the deflection of its shadow on a calibrated screen).**

FIGURE 1.52



Spheres A and B are touched by uncharge C and D respectively, as shown in Fig. 1 and D are then removed and B is broug to A to a distance of 5·0 cm between their as shown in Fig. 1.52(*c*). What is the repulsion of A on the basis of Coulomb Spheres A and C and spheres B and identical sizes. Ignore the sizes of A a comparison to separation between their

NCERT Solved Ex

Solution. Let the original repulsi between A and B be

$$F = \frac{k\,q_1\,q_2}{r^2}$$

As A and C have same size, charges a equally. Again, as B and D have same si charges are also shared equally.

As charges on A and B are halved, and between them is also halved from 10 cm therefore,

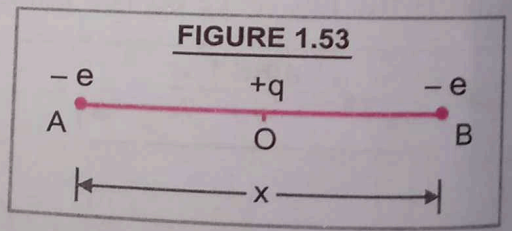
$$F' = \frac{k\,(q_1/2)\,(q_2/2)}{(r/2)^2} = \frac{k\,q_1\,q_2}{r^2} =$$

Example 9 **Two electrons and a charge q are held along a straight line. position and for what value of q will the sy in equilibrium ? Check whether it is unstable or neutral equilibrium.**

Solution. Let two electrons of charges be held at A and B. The third charge $+q$ placed at the centre O of AB. The forces on to two electrons being equal and opposite eachother and it is in equilibrium.

For the charge $(-e)$ at A to be in equil Fig. 1.53, force on *charge at A* due to $-e$ c B + force on charge at A due to $+q$ charge Zero

FIGURE 1.53



$$\frac{1}{4\pi\epsilon_0}\frac{(-e)\,(-e)}{x^2} + \frac{1}{4\pi\epsilon_0}\frac{q\,(-e)}{(x/2)^2}$$

or $$\frac{1}{4\pi\epsilon_0}\frac{e^2}{x^2} = \frac{1}{4\pi\epsilon_0}\frac{q\,(e)\times4}{x^2}$$

or $$e = 4\,q \quad \text{or} \quad \mathbf{q = e/4}$$

If charge at O is moved slightly towards A, it would not return to O on its own and shall continue to move towards A. Hence ***equilibrium is unstable.***

Example 10 **Two point charges 4 μC and 1 μC are separated by a distance of 2 m in air. Find the point on the line joining the charges at which net electric field of the system is zero.**

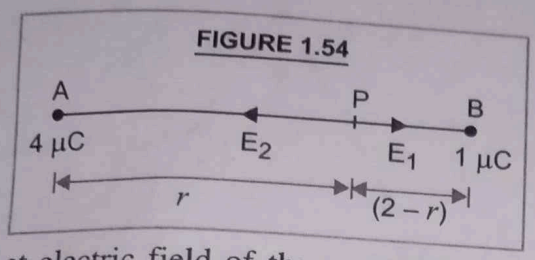
[CBSE 2017(C)]

Solution. Here, $q_1 = 4\ \mu C = 4 \times 10^{-6}$ C

$q_2 = 1\ \mu C = 10^{-6}$ C

$d = 2$ m

FIGURE 1.54



Let electric field of the system be zero at P, where $AP = r$, Fig. 1.54.

At P, $E_1 = E_2$

$$\therefore \quad \frac{q_1 \times 1}{4\pi\epsilon_0 r^2} = \frac{q_2 \times 1}{4\pi\epsilon_0 (2-r)^2}$$

$$\frac{4}{r^2} = \frac{1}{(2-r)^2} \quad \text{or} \quad \frac{2}{r} = \frac{1}{2-r}$$

$$r = 4 - 2r$$

$$3r = 4$$

$$r = \mathbf{4/3\ m}$$

YPE II SUPERPOSITION PRINCIPLE

rmula used. $\vec{F_0} = \vec{F_{01}} + \vec{F_{02}} + \vec{F_{03}} + ...$

its used. Force is in newton, when charges are coulomb and distance is in metre.

Example 11 **Ten positively charged par- are kept fixed on x-axis at points $x = 10$ cm, , 30 cm, ..., 100 cm. The first particle has e $1{\cdot}0 \times 10^{-8}$ C, second 8×10^{-8} C, third $27 \times$, and so on. Tenth particle will have charge 10^{-8} C. Find the magnitude of electric force on a 1C charge placed at the origin.**

olution. By superposition principle, force on 1 C placed at origin

$= F_{01} + F_{02} + ... + F_{010}$

$$= \frac{q_0}{4\pi\epsilon_0}\left[\frac{q_1}{r_1^2} + \frac{q_2}{r_2^2} + ... + \frac{q_{10}}{r_n^2}\right]$$

$$= 9\times10^9 \times 1\left[\frac{1{\cdot}0\times10^{-8}}{(0{\cdot}10)^2} + \frac{8\times10^{-8}}{(0{\cdot}20)^2} + \frac{27\times10^{-8}}{(0{\cdot}30)^2} + ... \frac{1000\times10^{-8}}{(1{\cdot}00)^2}\right]$$

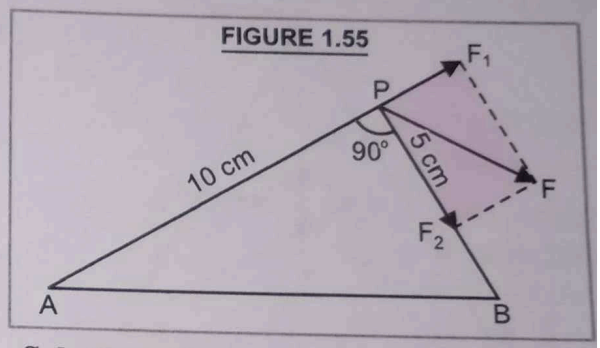
$= 9 \times 10^9 \times 10^{-6}\ [1 + 2 + 3 + ... + 10]$

$= 9 \times 10^3 \times 55 = \mathbf{4{\cdot}95 \times 10^5\ N}$

Example 12 **Find the magnitude of t resultant force on a charge of 1 μC held at P d to two charges of $+ 2 \times 10^{-8}$ C and $- 10^{-8}$ C a and B respectively.**

Given $AP = 10$ cm and $BP = 5$ cm. $\angle APB = 90°$, Fig. 1.55.

FIGURE 1.55



Solution. Here, $F = ?$,

Charge at P, $q = 1\ \mu C = 10^{-6}$ C

Charge at A, $q_1 = + 2 \times 10^{-8}$ C

Charge at B, $q_2 = - 10^{-8}$ C

AP = 10 *cm* = 0·1 *m*, BP = 5 *cm* = 0·0

$\angle APB = 90°$

Force at P due to q_1 charge at A,

$$F_1 = \frac{1}{4\pi\epsilon_0}\frac{q_1 q}{AP^2}, \text{ along } AP \text{ produced}$$

$$= \frac{9\times10^9 \times 2\times10^{-8} \times10^{-6}}{(0{\cdot}1)^2} = 18 \times 1$$

Force at P due to q_2 charge at B,

$$F_2 = \frac{1}{4\pi\epsilon_0}\frac{q_2 q}{BP^2}, \text{ along } PB$$

$$= \frac{9\times10^9 \times10^{-8} \times10^{-6}}{(0{\cdot}05)^2} = 36 \times 10^{-}$$

As angle between $\vec{F_1}$ and $\vec{F_2}$ is 90°,

$\therefore$ Resultant force, $F = \sqrt{F_1^2 + F_2^2}$

$= \sqrt{(18\times10^{-3})^2 + (36\times10^{-3})^2}$

$= 18 \times 10^{-3} \times 2{\cdot}236$

$= \mathbf{4{\cdot}0 \times 10^{-2}\ N}$

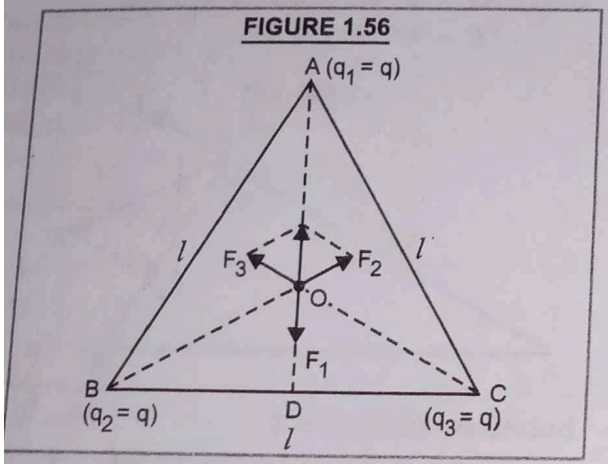
Example 13 **Consider three charges q_1, q_2, q_3 each equal to q at the vertices of an equilateral triangle of side l. What is the force on a charge Q (with the same sign as q) placed at the centroid of the triangle ?**

NCERT Solved Example

Solution. As shown in Fig. 1.56, draw AD $\perp$ BC.

$\therefore$ $\quad AD = AB \cos 30° = \dfrac{l\sqrt{3}}{2}$

FIGURE 1.56



Distance AO of the centroid O from A

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

$\therefore$ Force on Q at O due to charge $q_1 = q$ at A

$$F_1 = \frac{1}{4\pi\epsilon_0}\frac{Qq}{(l/\sqrt{3})^2} = \frac{3Qq}{4\pi\epsilon_0 l^2},\ \text{along AO}$$

Similarly, force on Q due to charge $q_2 = q$ at B

$$F_2 = \frac{3Qq}{4\pi\epsilon_0 l^2} \quad \text{along BO}$$

and force on Q due to charge $q_3 = q$ at C

$$F_3 = \frac{3Qq}{4\pi\epsilon_0 l^2},\ \text{along CO}$$

Angle between forces F_2 and $F_3 = 120°$

By parallelogram law, resultant of F_2 and

$$F_3 = \frac{3Qq}{4\pi\epsilon_0 l^2} \quad \text{along OA}$$

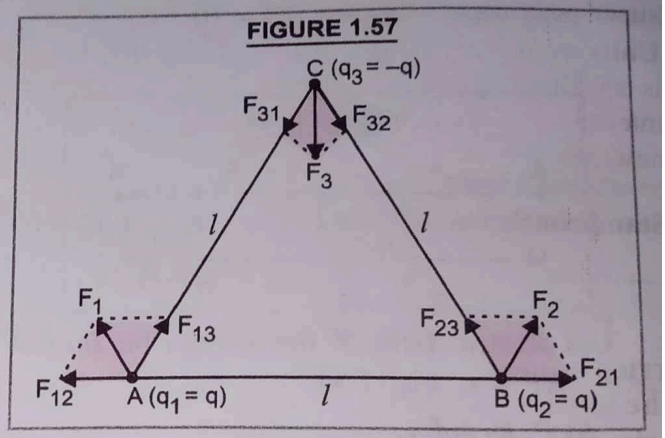
$\therefore$ Total force on $Q = \dfrac{3Qq}{4\pi\epsilon_0 l^2} - \dfrac{3Qq}{4\pi\epsilon_0 l^2} = 0$

Example 14 **Consider the charges q, q and $-q$ placed at the vertices of an equilateral triangle of each side l. What is the force on each charge ?**

NCERT Solved Example

Solution. As is clear from Fig. 1.57, force on $q_1 = q$ at A

FIGURE 1.57



$$\vec{F_1} = \vec{F_{12}} + \vec{F_{13}} = F\,\hat{r_1}$$

where $F = \dfrac{qq}{4\pi\epsilon_0 l^2}$

and $\hat{r_1}$ = unit vector along BC

Force on $(q_2 = q)$ at B,

$$\vec{F_2} = \vec{F_{21}} + \vec{F_{23}} = F\,\hat{r_2},$$

where $\hat{r_2}$ = unit vector along AC

Force on $q_3 = -q$ at C,

$$\vec{F_3} = \vec{F_{31}} + \vec{F_{32}}$$

$$= [\sqrt{F_1^2 + F_2^2 + 2F_1F_2\cos 60°}$$

$$= \sqrt{3}\,F\,\hat{n}$$

where $\hat{n}$ = unit vector along the direc bisecting $\angle$BCA.

We can show that

$$\vec{F_1} + \vec{F_2} + \vec{F_3} = 0$$

TYPE IV ELECTRIC FIELD AND RELATION BETWEEN ELECTRIC INTENSITY AND FORCE

Formulae used.

1. $|\vec{E}| = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}$ 2. $\vec{F} = q_0\vec{E}$

3. For calculating field due to any number of charges and continuous charge distributions, principle of super-position is applied.

Units used. The source charge q is in coulomb, so is test charge q_0. The distance r is in metre. Electric intensity E is in newton/coulomb and force F is in newton.

Standard value. $\frac{1}{4\pi\epsilon_0} = 9\times10^9\ \text{Nm}^2\,\text{C}^{-2}$

Example 15 **A free pith ball of mass 6 g carries a positive charge of (1/3) × 10^{-7} C. What is the nature and magnitude of charge that should be given to a second pith ball fixed 5 cm vertically below the former pith ball so that the upper pith ball is stationary.**

Solution. The upper pith ball will become stationary only when its weight acting downwards is balanced by the upward force of repulsion between the two pith balls. Let + q_2 be the charge given to lower pith ball.

Now, $q_1 = \frac{1}{3}\times10^{-7}$ C,

$r = 5$ cm $= 5\times10^{-2}$ m,

$m = 6$ g $= 6\times10^{-3}$ kg

When upper pith ball is stationary, F = mg

$$\therefore \quad \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2} = mg$$

$$\frac{9\times10^9\times\frac{1}{3}\times10^{-7}\,q_2}{(5\times10^{-2})^2} = 6\times10^{-3}\times9{\cdot}8$$

$$\frac{3\times10^2}{25\times10^{-4}}q_2 = 58{\cdot}8\times10^{-3}$$

$$q_2 = \frac{58{\cdot}8\times25}{3}\times10^{-9} = \mathbf{4{\cdot}90\times10^{-7}\ C}$$

Example 16 **A small sphere of mass 1 g ries a charge of + 6 μC. The sphere is suspended string in an electric field of 400 NC^{-1} acting nwards. Calculate tension in the string. What will be the tension if charge on the sphere were − 6 μC ?**

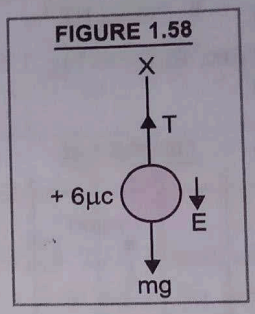
Solution. Here, $m = 1\ g = 10^{-3}$ kg,

$q = +6\ \mu C = +6\times10^{-6}$ C

$E = 400\ NC^{-1}$, downwards.

As is clear from Fig. 1.58,

FIGURE 1.58



$$T = F_e + mg = qE + mg$$
$$= 6\times10^{-6}\times400 + 10^{-3}\times9{\cdot}8$$
$$= 122\times10^{-4}\ \text{N} = 1{\cdot}22\times10^{-2}\ \text{N}$$

However, when $q = -6\ \mu C$, force due to electric field is upwards.

$\therefore\ T + F_e = mg$

or $T = mg - F_e = 9{\cdot}8\times10^{-3} - 24\times10^{-4}$

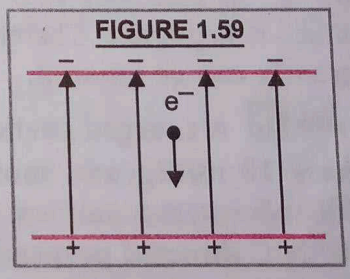
$= \mathbf{74\times10^{-4}\ N}$

Example 17 **An electron falls through a distance of 1·5 cm in a uniform electric field of value 2 × 10^4 N/C. When the direction of electric field is reversed, a proton falls through the same distance. Compare the time of fall in each case. Contrast the situation with that of 'free fall under gravity'.** **[CBSE 2018 (C)]**

NCERT Solved Example

Solution. *(a)* ***For electron,*** Refer to Fig. 1.59

FIGURE 1.59



$y_1 = 1{\cdot}5$ cm $= 1{\cdot}5\times10^{-2}$ m, $E_1 = 2\times10^4$ N/

$q_0 = (-)\ 1{\cdot}6\times10^{-19}$ coulomb, $m_1 = 9\times10^{-31}$

Acceleration, $a_1 = \frac{F_1}{m_1} = \frac{q_0 E_1}{m_1}$

$$= \frac{1{\cdot}6\times10^{-19}\times2\times10^4}{9\times10^{-31}} = 3{\cdot}55\times10^{15}\ \text{m/s}^2$$

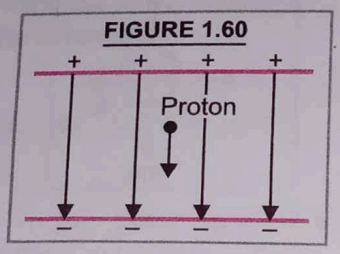
From $y_1 = u_1 t_1 + \frac{1}{2} a_1 t_1^2$

$$y_1 = 0 + \frac{1}{2} a_1 t_1^2$$

or $t_1 = \sqrt{2\frac{y_1}{a_1}} = \sqrt{\frac{2\times1{\cdot}5\times10^{-2}}{3{\cdot}55\times10^{15}}} = \mathbf{2{\cdot}9 \times 10^{-9}}$ **sec.**

(b) ***For proton,*** Refer to Fig. 1.60, when electric field is reversed.

FIGURE 1.60



Charge $q_0 = +1{\cdot}6 \times 10^{-19}$ C,

$m_2 = 1{\cdot}67 \times 10^{-27}$ kg.

$\therefore$ Acceleration, $a_2 = \frac{F_2}{m_2} = \frac{q_0 E_2}{m_2}$

$$a_2 = \frac{1{\cdot}6\times10^{-19}\times2\times10^4}{1{\cdot}67\times10^{-27}} = 1{\cdot}92 \times 10^{12} \text{ m/s}^2$$

Similarly, $t_2 = \sqrt{\frac{2\,y_2}{a_2}} = \sqrt{\frac{2\times1{\cdot}5\times10^{-2}}{1{\cdot}92\times10^{12}}}$

$= 1{\cdot}25 \times 10^{-7}$ s

and $\frac{t_1}{t_2} = \frac{2{\cdot}9\times10^{-9}}{1{\cdot}25\times10^{-7}} = \mathbf{2{\cdot}3 \times 10^{-2}}$

We observe that acceleration of electron $\approx 10^{15}$ m/s^2 and acceleration of proton $\approx 10^{12}$ m/s^2. The value of 'g' in free fall is only 9·8 m/s^2 $\approx 10^1$ m/s^2, which is negligible. Therefore, **effect of acc. due to gravity can be ignored.**

Example 18 **A charged particle of charge μC and mass 10 milligram, moving with a velocity of 1000 m/s enters a uniform electric field of strength 10^3 N/C directed perpendicular to its direction of motion. Find the velocity and displacement of the particle after 10 s.**

(CBSE Sample Paper 2011)

Solution. Here, $q = 2\ \mu\text{C} = 2 \times 10^{-6}$ C,

$m = 10$ mg $= 10^{-5}$ kg

$v_x = 1000$ m/s, $E_y = 10^3$ N/C

$$v_y = u_y + a_y t = 0 + \frac{q E_y t}{m}$$

$$= \frac{2\times10^{-6}\times10^3\times10}{10^{-5}} = 2000 \text{ m/s}$$

As v_x remains constant, therefore, net velo after 10 s

$$= \sqrt{v_x^2 + v_y^2} = \sqrt{(1000)^2 + (2000)^2}$$

$$= \mathbf{1000\sqrt{5}\ m/s}$$

Displacement along x-axis after 10 s

$x = v_x t = 1000 \times 10 = 10000$ m

Displacement along y-axis after 10 s

$$y = u_y \times t + \frac{1}{2}\frac{q E_y}{m} t^2$$

$$= 0 + \frac{1}{2}\times\frac{2\times10^{-6}\times10^3}{10\times10^{-6}}(10^2) = 10000$$

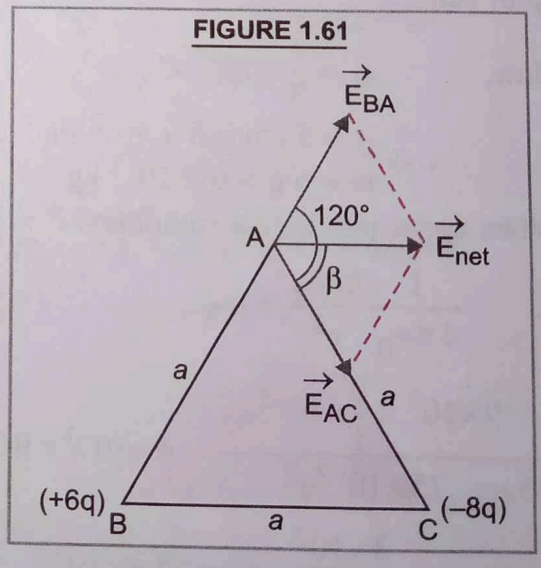
Net displacement $= \sqrt{x^2 + y^2}$

$$= \sqrt{(10000)^2 + (10000)^2} = \mathbf{10000\sqrt{2}}$$

Example 19 **Two point charges + 6 q – 8 q are placed at the vertices B and C o equilateral triangle ABC of side a. Obtai expression for magnitude and directio resultant electric field at the vertex A due to two charges.** **[CBSE 2014**

Solution. As is clear from Fig. 1.61.

FIGURE 1.61



$$E_{BA} = \frac{1}{4\pi\epsilon_0}\frac{6q\times1}{a^2} = 6E$$

$$E_{AC} = \frac{1}{4\pi\epsilon_0}\frac{8q}{a^2} = 8E$$

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

Magnitude of resultant field is

$$E_{net} = \sqrt{E_{BA}^2 + E_{AC}^2 + 2E_{BA}E_{AC}\cos 120^\circ}$$

$$= \sqrt{(6E)^2 + (8E)^2 + 2\times 6E\times 8E\left(-\frac{1}{2}\right)}$$

$$E_{net} = E\sqrt{52} = \frac{q\sqrt{52}}{4\pi\epsilon_0 a^2}$$

Let the resultant field make an angle β with AC.

$$\tan\beta = \frac{E_{BA}\sin 120^\circ}{E_{AC} + E_{BA}\cos 120^\circ}$$

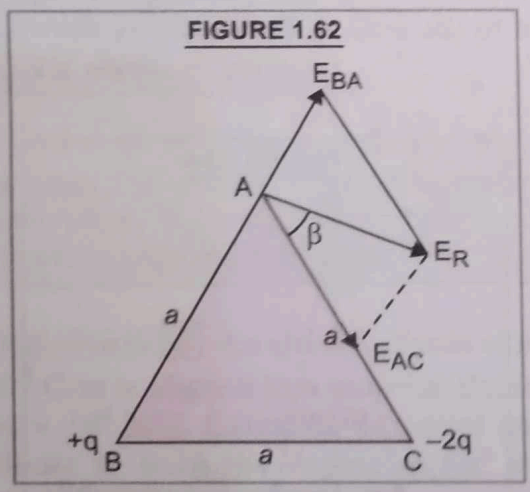
$$= \frac{6E\sqrt{3}/2}{8E + 6E\left(-\frac{1}{2}\right)} = \frac{3\sqrt{3}}{5}$$

$$\beta = \tan^{-1}\left(\frac{3\sqrt{3}}{5}\right)$$

Example 20 **Two point charges + q and - 2 q are placed at the vertices B and C of an equilateral triangle ABC of side a. Obtain the expression for magnitude and direction of resultant electric field at the vertex A due to these two charges.** [CBSE 2014 (C)]

Solution. In Fig. 1.62, imagine a charge of + 1 C at A.

FIGURE 1.62



$$E_{BA} = \frac{1}{4\pi\epsilon_0}\frac{q\times 1}{a^2} = E, \text{ along } BAE$$

and $$E_{AC} = \frac{-2q}{4\pi\epsilon_0 a^2} = -2E, \text{ along } AC$$

$$\theta = 120^\circ$$

Resultant electric field at A

$$E_R = \sqrt{E_{BA}^2 + E_{AC}^2 + 2E_{BA}\cdot E_{AC}\cos 120^\circ}$$

$$= \sqrt{E^2 + (-2E)^2 + 2E(2E)\left(-\frac{1}{2}\right)}$$

$$E_R = E\sqrt{3} = \frac{q\sqrt{3}}{4\pi\epsilon_0 a^2}$$

If β is angle which E_R makes with AC, then

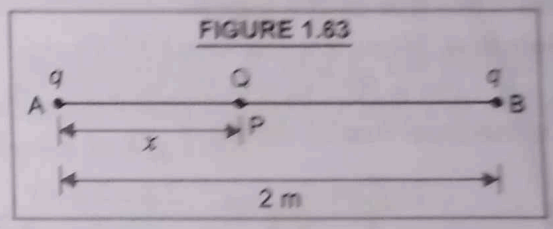
$$\tan\beta = \frac{E_{BA}\sin\theta}{E_{AC} + E_{BA}\cos\theta} = \frac{E\sin 120^\circ}{2E + E\cos 120^\circ}$$

$$= \frac{E\sqrt{3}/2}{E\left(2 - \frac{1}{2}\right)} = \frac{1}{\sqrt{3}} \quad \therefore \beta = 30^\circ$$

Example 21 **Two identical point charges q each, are kept 2 m apart in air. A third point charge Q of unknown magnitude and sign is placed on the line joining the charges such that the system remains in equilibrium. Find the position and nature of Q.** [CBSE 2

Solution. In Fig. 1.63, two identical point charges, q each are placed at A, B, where $AB =$ Let a third point charge Q be placed at P on the AB such that $AP = x$. Therefore, $BP = (2 - x)$.

FIGURE 1.63



The charge Q will be in equilibrium when repelled/attracted equally by the two charges at B. Therefore, it must be at the centre of AB. it m positive or negative.

Again, charge q at B will be in equilibrium.

$$\frac{kQq}{1^2} + \frac{kqq}{2^2} = 0 \quad \text{or} \quad \frac{Q}{1} + \frac{q}{4} = 0 \quad \text{or } Q =$$

TYPE V ELECTRIC DIPOLE, DIPO MOMENT, DIPOLE FI

Formulae used.

1. Dipole moment $|\vec{p}| = q\times 2a$, where

$2a$ = distance between two point charges of d

2. Dipole field intensity on axial line of dipo

$$|\vec{E}_1| = \frac{2|\vec{p}|r}{4\pi\epsilon_0 (r^2 - a^2)^2}$$

where r is distance of the point from the centre of the dipole.

3. Dipole field intensity on equatorial line of dipole

$$|\vec{E_2}| = \frac{|\vec{p}|}{4\pi\epsilon_0 (r^2 + a^2)^{3/2}}$$

4. Dipole field intensity at any point due to a short dipole is $|\vec{E}| = \frac{|\vec{p}|}{4\pi\epsilon_0 r^3}\sqrt{3\cos^2\theta + 1}$,

and $\tan\alpha = \frac{1}{2}\tan\theta$,

where θ is the angle which the line joining the point to centre of dipole makes with the axis of dipole.

And α is the angle at which $\vec{E}$ is inclined to the line joining the point to the centre of dipole.

Units used. q in coulomb, $2a$ in metre, $|\vec{p}|$ in coulomb metre (C-m), r in metre, E_1, E_2 are in newton/coulomb

Example 22 **Two charges each of 1 μ C but opposite in sign are 1 cm apart. Calculate electric field at a point distant 10 cm from the mid point on axial line of the dipole.**

Solution. Here, $q = 1\ \mu C = 10^{-6}$ C,
$2a = 1$ cm $= 10^{-2}$ m, $r = 10$ cm $= 10^{-1}$ m
On the axial line of dipole,

$$E = \frac{2|\vec{p}|r}{4\pi\epsilon_0 (r^2 - a^2)^2} = \frac{2q \times 2a \times r}{4\pi\epsilon_0 (r^2 - a^2)^2}$$

$$= \frac{9\times10^9 \times 2\times10^{-6} \times 10^{-2} \times 10^{-1}}{(10^{-2} - 0{\cdot}25\times10^{-4})^2}$$

$$= \frac{18}{10^{-4}(1 - 0{\cdot}0025)^2}$$

$$E = \frac{18\times10^4}{0{\cdot}9975\times0{\cdot}9975} = \mathbf{18 \times 10^4\ N/C}$$

Example 23 **Two charges + 20 μ C and 0 μ C are held 1 cm apart. Calculate the electric d at a point on the equatorial line at a distance 50 cm from the centre of the dipole.**

Solution. Here, $q = \pm 20\ \mu C = \pm 20 \times 10^{-6}$ C,

$2a = 1$ cm $= 10^{-2}$ m, $r = 50$ cm $= \frac{1}{2}$ m

As $2a << r$, therefore, intensity on equatorial of short dipole is

$$E = \frac{1}{4\pi\epsilon_0}\frac{p}{r^3} = \frac{q\times2a}{4\pi\epsilon_0 r^3}$$

$$= \frac{9\times10^9 \times 20\times10^{-6} \times 10^{-2}}{(1/2)^3}$$

$$E = \mathbf{1{\cdot}44 \times 10^4\ N/C}$$

Example 24 **What is the magnitude electric intensity due to a dipole of moment 2 10^{-8} C-m at a point distant 1 m from the centre dipole, when line joining the point to the centre dipole makes an angle of 60° with dipole axis ?**

Solution. Here, $p = 2 \times 10^{-8}$ C-m, $r = 1$ m, $\theta = 60°$, $E = ?$

$$E = \frac{p}{4\pi\epsilon_0 r^3}\sqrt{3\cos^2\theta + 1}$$

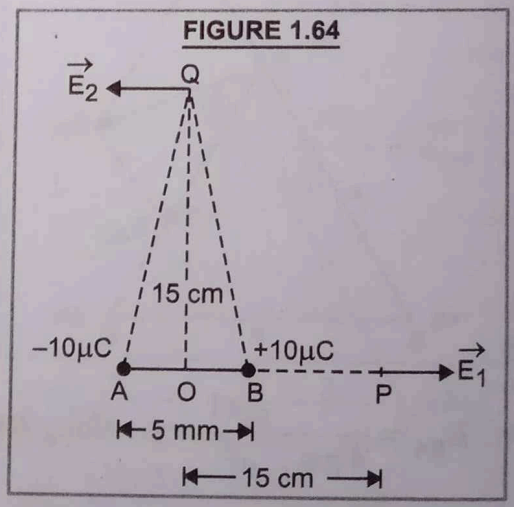
$$= \frac{2\times10^{-8} \times 9\times10^9}{1^3}\sqrt{3(\cos 60°)^2 +}$$

$$E = \mathbf{238{\cdot}1\ N/C}$$

Example 25 **Two charges ± 10 μ C a placed 5·0 mm apart. Determine the electric fi at (a) a point P on the axis of dipole 15 cm aw from its centre on the side of the positive char as shown in Fig. 1.64 and at (b) a point Q, 15 away from O on a line passing through O a normal to the axis of the dipole as shown in F 1.64.**

NCERT Solved Exampl

FIGURE 1.64



Solution. Here, $q = \pm 10\ \mu C = \pm 10^{-5}$ C
$2a = 5{\cdot}0$ mm $= 5 \times 10^{-3}$ m
$r = OP = 15$ cm $= 15 \times 10^{-2}$
$|\vec{p}| = q \times 2a = 10^{-5} \times 5 \times 10$
$= \mathbf{5 \times 10^{-8}}$ C-m

(*a*) As P lies on axial line of dipole,

$$\therefore \quad E_1 = \frac{2|\vec{p}|r}{4\pi\epsilon_0 (r^2 - a^2)^2}, \text{ along } BP$$

As $a << r$, $\therefore$

$$E_1 = \frac{2|\vec{p}|}{4\pi\epsilon_0 r^3} = \frac{2\times5\times10^{-8}\times9\times10^9}{(15\times10^{-2})^3}$$

$$= \mathbf{2{\cdot}67 \times 10^5\ N/C, along\ BP}$$

(*b*) As Q lies on equatorial line of dipole,

$$\therefore \quad E_2 = \frac{|\vec{p}|}{4\pi\epsilon_0 (r^2 + a^2)^{3/2}} = \frac{|\vec{p}|}{4\pi\epsilon_0 r^3}$$

$(\because\ a << r)$

$$= \frac{1}{2}E_1 = \frac{1}{2}\times2{\cdot}67\times10^5 = \mathbf{1{\cdot}33 \times 10^5\ N/C}$$

$\vec{E_2}$ **is along a line parallel to** ***BA*** as shown in g. 1.64.

TYPE VI TORQUE ON DIPOLE AND POTENTIAL ENERGY OF DIPOLE IN ELECTRIC FIELD

Formulae used. 1. Torque, $\tau = pE \sin\theta$, where θ is angle between $\vec{p}$ and $\vec{E}$

2. Potential energy of dipole,

$$U = -pE(\cos\theta_2 - \cos\theta_1)$$

where θ_1 is initial angle between $\vec{p}$ and $\vec{E}$, and θ_2 is final angle between $\vec{p}$ and $\vec{E}$.

Units used. p in coulomb-metre, E in newton/coulomb ; θ, θ_1, θ_2 in degrees ; τ in newton-metre and U in joule.

Example 26 **An electric dipole of moment 10^{-8} C-m is aligned in a uniform electric field $1{\cdot}44 \times 10^4$ N/C. Calculate potential energy of dipole to hold the dipole at 60° with the direction of electric field.**

Solution. Here, $p = 5 \times 10^{-8}$ *C-m*, $\theta_1 = 0°$,

$E = 1{\cdot}44 \times 10^4$ N/C, $\theta_2 = 60°$, *P.E.* = ?

$$P.E. = -pE(\cos\theta_2 - \cos\theta_1)$$

$$= -5\times10^{-8}\times1{\cdot}44\times10^4(\cos60° - \cos0°)$$

$$P.E. = -7{\cdot}2\times10^{-4}(0{\cdot}5 - 1)$$

$$= \mathbf{3{\cdot}6 \times 10^{-4}\ J}$$

Example 27 **An electric dipole of dipole ment 4×10^{-5} Cm is placed in a uniform electric field of 10^{-3} N/C making an angle of 30° with the direction of the field. Determine the torque exerted by the electric field on the dipole.**

(Hr. Board 2002)

Solution. Here, $p = 4 \times 10^{-5}$ C.m,

$E = 10^{-3}$ N/C, $\theta = 30°$

$$\tau = pE\sin\theta$$

$$= (4\times10^{-5})\,10^{-3}\sin30°$$

$$= \mathbf{2 \times 10^{-8}\ N\text{-}m}$$

TYPE VII ELECTRIC FLUX AND GAUSS'S THEOREM IN ELECTROSTATICS

Formulae used.

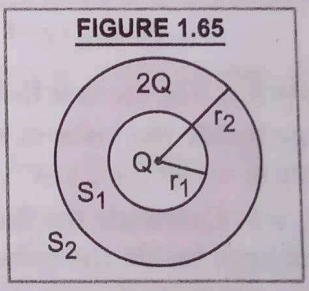
1. $\phi_E = \oint_S \vec{E}.\vec{ds} = E\,s\cos\theta$, where θ is angle which normal to the area makes with $\vec{E}$.

2. $\phi_E = \oint \vec{E}.\vec{ds} = \frac{Q}{\epsilon_0}$, where Q is total charge (*i.e.* algebraic sum of all the charges) inside the closed surface.

Units used. E is in NC^{-1} ; s in m^2 ; ϕ_E in $NC^{-1}\,m^2$.

Example 28 **S_1 and S_2 are two concentric spheres enclosing charges Q and 2 Q respectively as shown in Fig.1.65.**

FIGURE 1.65



(*i*) What is the ratio of electric flux through S_1 and S_2 ?

(*ii*) How will the electric flux through the sphere S_1 change, if a medium of dielectric constant K is introduced in the space inside S_1 in place of air ?

(*iii*) How will the electric flux through sphere S_1 change, if a medium of dielectric constant K is introduced in the space inside S_2 in place of air ?

(CBSE 2014

Solution. (*i*) From Gauss's theorem

electric flux through S_1 is $\phi_1 = \frac{Q}{\epsilon_0}$