# Previous Years' CBSE Board Questions

## 1.6 Coulomb's Law

**VSA (1 mark)**

1. Two identical conducting balls $A$ and $B$ have charges $-Q$ and $+3Q$ respectively. They are brought in contact with each other and then separated by a distance $d$ apart. Find the nature of the Coulomb force between them. *(AI 2019)*

2. Two equal balls having equal positive charge '$q$' coulombs are suspended by two insulating strings of equal length. What would be the effect on the force when a plastic sheet is inserted between the two? *(AI 2014)*

**SA I (2 marks)**

3. Plot a graph showing the variation of coulomb force ($F$) versus $\left(\frac{1}{r^2}\right)$, where $r$ is the distance between the two charges of each pair of charges : (1μC, 2μC) and (2μC, – 3μC), interpret the graphs obtained. *(AI 2011)*

**LA (5 marks)**

4. 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 $Q$. *(3/5, Delhi 2019)*

## 1.8 Electric Field

**LA (5 marks)**

5. Consider a system of $n$ charges $q_1, q_2 .... q_n$ with position vectors $\vec{r}_1, \vec{r}_2, \vec{r}_3, .... \vec{r}_n$ relative to some origin '$O$'. Deduce the expression for the net electric field $\vec{E}$ at a point $P$ with position vector $\vec{r}_p$ due to this system of charges. *(3/5, Foreign 2015)*

## 1.9 Electric Field Lines

**VSA (1 mark)**

6. Draw the pattern of electric field lines when a point charge $+q$ is kept near an uncharged conducting plate. *(Delhi 2019)*

7. Why do the electrostatic field lines not form closed loops ? *(AI 2014, AI 2012C)*

8. Why do the electric field lines never cross each other ? *(AI 2014)*

**SA II (3 marks)**

9. A point charge (+$Q$) is kept in the vicinity of an uncharged conducting plate. Sketch the electric field lines between the charge and the plate. *(1/3, Foreign 2014)*

## 1.10 Electric Flux

**VSA (1 mark)**

10. Write an expression for the flux $\Delta\phi$, of the electric field $\vec{E}$ through an area element $\Delta\vec{S}$. *(Delhi 2010C)*

**SA I (2 marks)**

11. (i) Define the term 'electric flux'. Write its SI unit.

    (ii) What is the flux due to electric field $\vec{E} = 3\times10^3\hat{i}$ N/C through a square of side 10 cm, when it is held normal to $\vec{E}$ ? *(AI 2015C)*

12. Given a uniform electric field $\vec{E} = 5\times10^3\,\hat{i}$ N/C. Find the flux of this field through a square of 10 cm on a side whose plane is parallel to the $y$-$z$ plane. What would be the flux through the same square if the plane makes a 30° angle with the $x$-axis? *(Delhi 2014)*

**SA II (3 marks)**

13. Consider a uniform electric field $\vec{E} = 3\times10^3\hat{i}$ N/C. Calculate the flux of this

field through a square surface of area 10 $cm^2$ when

(i) its plane is parallel to the $y$-$z$ plane

(ii) the normal to its plane makes a 60° angle with the $x$-axis. *(Delhi 2013C)*

## 1.11 Electric Dipole

**VSA (1 mark)**

**14.** Define the term electric dipole moment of a dipole. State its S.I. unit. *(Foreign 2013, AI 2011)*

**SA II (3 marks)**

**15.** Derive an expression for the electric field due to dipole of dipole moment $\vec{p}$ at a point on its perpendicular bisector. (2/3, *Delhi 2019*)

**16.** Derive the expression for electric field at a point on the equatorial line of an electric dipole. (2/3, *Delhi 2017*)

**LA (5 marks)**

**17.** Derive an expression for the electric field at any point on the equatorial line of an electric dipole. (2/5, *Delhi 2019*)

**18.** (a) Derive an expression for the electric field $E$ due to a dipole of length '$2a$' at a point distant $r$ from the centre of the dipole on the axial line.

(b) Draw a graph of $E$ versus $r$ for $r >> a$. (3/5, *AI 2017*)

**19.** An electric dipole of dipole moment $\vec{p}$ consists of point charges $+q$ and $-q$ separated by a distance $2a$ apart. Deduce the expression for the electric field $\vec{E}$ due to the dipole at a distance $x$ from the centre of the dipole on its axial line in terms of the dipole moment $\vec{p}$. Hence show that in the limit $x >> a$, $\vec{E} \longrightarrow 2\vec{p}/(4\pi\varepsilon_0 x^3)$.

(3/5, *Delhi 2015*)

**20.** Find the resultant electric field due to an electric dipole of dipole moment $2aq$ ($2a$ being the separation between the charges $\pm q$) at a point distance $x$ on its equator. (2/5, *Foreign 2015*)

**21.** Define electric dipole moment. Is it a scalar or a vector quantity? Derive the expression for the electric field of a dipole at a point on the equatorial plane of the dipole. (3/5, *AI 2013*)

## 1.12 Dipole in a Uniform External Field

**VSA (1 mark)**

**22.** Write the expression for the torque $\vec{\tau}$ acting on a dipole of dipole moment $\vec{p}$ placed in an electric field $\vec{E}$. *(Foreign 2015)*

**SA II (3 marks)**

**23.** Depict the orientation of the dipole in (a) stable, (b) unstable equilibrium in a uniform electric field. (1/3, *Delhi 2017*)

**24.** (i) Obtain the expression for the torque $\vec{\tau}$ experienced by an electric dipole of dipole moment $\vec{p}$ in a uniform electric field, $\vec{E}$.

(ii) What will happen if the field were not uniform? *(Delhi 2017)*

**25.** An electric dipole of dipole moment $\vec{p}$ is placed in a uniform electric field $\vec{E}$. Obtain the expression for the torque $\vec{\tau}$ experienced by the dipole. Identify two pairs of perpendicular vectors in the expression. *(Delhi 2015C)*

**26.** An electric dipole is kept in a uniform electric field. Derive an expression for the net torque acting on it and write its direction. State the conditions under which the dipole is in (i) stable equilibrium and (ii) unstable equilibrium. *(Delhi 2012C)*

**LA (5 marks)**

**27.** If dipole were kept in a uniform external electric field $E_0$, diagrammatically represent the position of the dipole in stable and unstable equilibrium and write the expressions for the torque acting on the dipole in both the cases. (2/5, *AI 2017*)

**28.** (a) Define torque acting on a dipole of dipole moment $\vec{p}$ placed in a uniform electric field $\vec{E}$. Express it in the vector form and point out the direction along which it acts.

(b) What happens if the field is non-uniform?

(c) What would happen if the external field $\vec{E}$ is increasing (i) parallel to $\vec{p}$ and (ii) anti-parallel to $\vec{p}$ ? *(Foreign 2016)*

**29.** Deduce the expression for the torque acting on a dipole of dipole moment $\vec{p}$ in the presence of a uniform electric field $\vec{E}$.
*(3/5, AI 2014)*

## 1.13 Continuous Charge Distribution

**SA I (2 marks)**

**30.** Deduce the expression for the electric field $\vec{E}$ due to a system of two charges $q_1$ and $q_2$ with position vectors $\vec{r}_1$ and $\vec{r}_2$ at a point $\vec{r}$ with respect to the common origin O.
*(Delhi 2010C)*

## 1.14 Gauss's Law

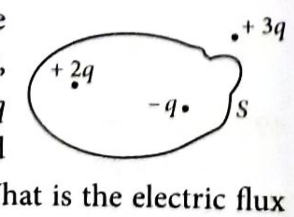
**VSA (1 mark)**

**31.** How does the electric flux due to a point charge enclosed by a spherical Gaussian surface get affected when its radius is increased ? *(Delhi 2016)*

**32.** What is the electric flux through a cube of side 1 cm which encloses an electric dipole?
*(Delhi 2015)*

**33.** A charge '$q$' is placed at the centre of a cube of side $l$. What is the electric flux passing through each face of the cube ? *(AI 2012)*

**34.** Figure shows three point charges, $+2q$, $-q$, $+3q$. Two charges $+2q$ and $-q$ are enclosed within a surface '$S$'. What is the electric flux due to this configuration through the surface '$S$' ? *(Delhi 2010)*




**35.** A charge Q μC is placed at the centre of a cube. What is the electric flux coming out from any one surface ? *(AI 2010)*

**SA I (2 marks)**

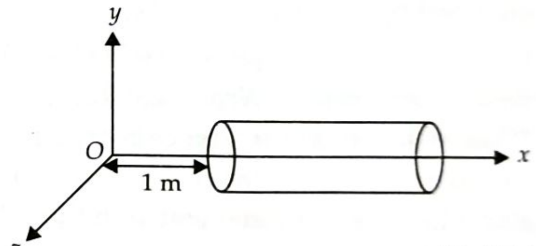
**36.** Show that the electric field at the surface of a charged conductor is given by $\vec{E} = \frac{\sigma}{\varepsilon_0}\hat{n}$, where $\sigma$ is the surface charge density and $\hat{n}$ is a unit vector normal to the surface in the outward direction. *(AI 2010)*

**SA II (3 marks)**

**37.** A hollow cylindrical box of length 1 m and area of cross-section 25 $cm^2$ is placed in a three dimensional coordinate system as shown in the figure. The electric field in the region is given by $\vec{E} = 50x\hat{i}$, where $E$ is in N $C^{-1}$ and $x$ is in metres. Find

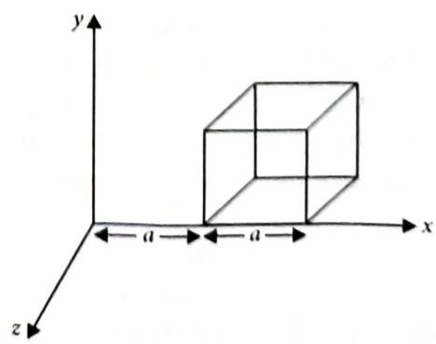
(i) net flux through the cylinder.

(ii) charge enclosed by the cylinder.




*(Delhi 2013)*

**38.** State Gauss's law in electrostatic. A cube with each side '$a$' is kept in an electric field given by $\vec{E} = Cx\hat{i}$, (as is shown in the figure) where C is a positive dimensional constant. Find out



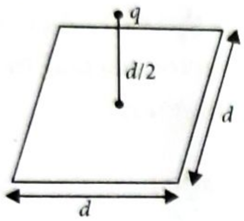

(i) the electric flux through the cube

(ii) the net charge inside the cube.

*(Foreign 2012)*

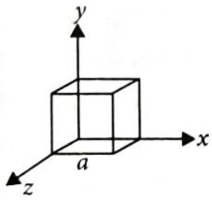
**LA (5 marks)**

39. (a) Define electric flux. Is it a scalar or a vector quantity ?
A point charge $q$ is at a distance of $d/2$ directly above the centre of a square of side $d$, as shown in the figure. Use Gaus's law to obtain the expression for the electric flux through the square.




(b) If the point charge is now moved to a distance '$d$' from the centre of the square and the side of the square is doubled, explain how the electric flux will be affected. *(2018)*

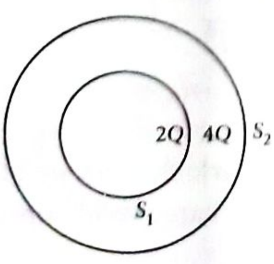
40. Given the electric field in the region $\vec{E} = 2x\hat{i}$, find the electric flux through the cube and the charge enclosed by it.




*(2/5, Delhi 2015)*

41. Define electric flux. Write its S.I. unit.
"Gauss's law in electrostatics is true for any closed surface, no matter what its shape or size is". Justify this statement with the help of a suitable example. *(AI 2015)*

42. Consider two hollow concentric spheres $S_1$ and $S_2$, enclosing charges $2Q$ and $4Q$ respectively as shown in figure.
(i) Find out the ratio of the electric flux through them.
(ii) How will the electric flux through the sphere $S_1$ change if a medium of dielectric constant '$\varepsilon_r$' is introduced in the space inside $S_1$ in place of air? Deduce the necessary expression.




*(AI 2014)*

## 1.15 Applications of Gauss's Law

**VSA (1 mark)**

43. A metallic spherical shell has an inner radius $R_1$ and outer radius $R_2$. A charge $Q$ is placed at the centre of the shell. What will be the surface charge density on the (i) inner surface, and (ii) outer surface of the shell? *(AI 2019)*

44. Does the charge given to a metallic sphere depend on whether it is hollow or solid. Give reason for your answer. *(Delhi 2017)*

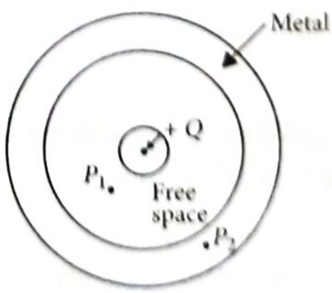
45. Two charges of magnitudes $-2Q$ and $+Q$ are located at points $(a, 0)$ and $(4a, 0)$ respectively. What is the electric flux due to these charges through a sphere of radius '$3a$' with its centre at the origin? *(AI 2013)*

**SA I (2 marks)**

46. Apply Gauss's law to show that for a charged spherical shell, the electric field outside the shell is, as if the entire charge were concentrated at the centre. *(AI 2019)*

47. Two large parallel plane sheets have uniform charge densities $+\sigma$ and $-\sigma$. Determine the electric field (i) between the sheets, and (ii) outside the sheets. *(AI 2019)*

48. A small metal sphere carrying charge $+Q$ is located at the centre of a spherical cavity inside a large uncharged metallic spherical shell as shown in the figure. Use Gauss's law to find the expressions for the electric field at points $P_1$ and $P_2$.




*(AI 2014)*

49. Two concentric metallic spherical shells of radii $R$ and $2R$ are given charges $Q_1$ and $Q_2$ respectively. The surface charge densities on the outer surfaces of the shells are equal. Determine the ratio $Q_1 : Q_2$. *(Foreign 2013)*

**50.** A spherical conducting shell of inner radius $r_1$ and outer radius $r_2$ has a charge $Q$. A charge $q$ is placed at the centre of the shell.

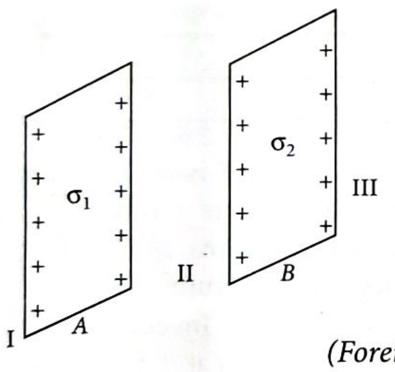
(a) What is the surface charge density on the (i) inner surface, (ii) outer surface of the shell?

(b) Write the expression for the electric field at a point $x > r_2$ from the centre of the shell.

*(AI 2010)*

## SA II (3 marks)

**51.** Two infinitely large plane thin parallel sheets having surface charge densities $\sigma_1$ and $\sigma_2$ $(\sigma_1 > \sigma_2)$ are shown in the figure. Write the magnitudes and directions of the net electric fields in the regions marked II and III.




*(Foreign 2014)*

**52.** (i) State Gauss's law.

(ii) A thin straight infinitely long conducting wire of linear charge density '$\lambda$' is enclosed by a cylindrical surface of radius '$r$' and length '$l$'. Its axis coinciding with the length of the wire. Obtain the expression for the electric field, indicating its direction, at a point on the surface of the cylinder. *(Delhi 2012C)*

**53.** Using Gauss's law obtain the expression for the electric field due to a uniformly charged thin spherical shell of radius $R$ at a point outside the shell. Draw a graph showing the variation of electric field with $r$, for $r > R$ and $r < R$.

*(Delhi 2011)*

## LA (5 marks)

**54.** (a) Use Gauss' law to derive the expression for the electric field $(\vec{E})$ due to a straight uniformly charged infinite line of charge density $\lambda$ C m$^{-1}$.

(b) Draw a graph to show the variation of $E$ with perpendicular distance $r$ from the line of charge.

(c) Find the work done in bringing a charge $q$ from perpendicular distance $r_1$ to $r_2$ $(r_2 > r_1)$. *(2018)*

**55.** Use Gauss's theorem to find the electric field due to a uniformly charged infinitely large plane thin sheet with surface charge density $\sigma$. *(2/5, AI 2017)*

**56.** Use Gauss's law to find the electric field due to a uniformly charged infinite plane sheet. What is the direction of field for positive and negative charge densities? *(3/5, AI 2016)*

**57.** Use Gauss's law to prove that the electric field inside a uniformly charged spherical shell is zero.

*(3/5, AI 2015)*

**58.** A small conducting sphere of radius '$r$' carrying a charge $+q$ is surrounded by a large concentric conducting shell of radius $R$ on which a charge $+Q$ is placed. Using Gauss's law derive the expressions for the electric field at a point '$x$'

(i) between the sphere and the shell $(r < x < R)$.

(ii) outside the spherical shell.

*(3/5, Foreign 2015)*

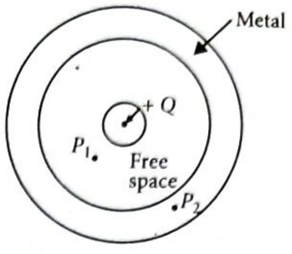
**59.** Using Gauss' law deduce the expression for the electric field due to a uniformly charged spherical conducting shell of radius $R$ at a point (i) outside and (ii) inside the shell. Plot a graph showing variation of electric field as a function of $r > R$ and $r < R$. ($r$ being the distance from the centre of the shell). *(AI 2013)*

**60.** Using Gauss's law, derive the expression for the electric field at a point (i) outside and (ii) inside a uniformly charged thin spherical shell. Draw a graph showing electric field $\vec{E}$ as a function of distance from the centre.

*(AI 2013C)*

**61.** (i) Define electric flux. Write its S.I. unit.

(ii) A small metal sphere carrying charge $+Q$ is located at the centre of a spherical cavity inside a large uncharged metallic spherical shell as shown in the figure. Use Gauss's law to find the expressions for the electric field at points $P_1$ and $P_2$.




(iii) Draw the pattern of electric field lines in this arrangement. *(AI 2012C)*

## Detailed Solutions

**1.** Final charge on each ball

$$= \frac{q_A + q_B}{2} = \frac{-Q+3Q}{2} = +Q$$

As both the balls have same nature of charges, hence nature of the Coulomb force is repulsive.

**2.** As in air, $F = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{r^2}$

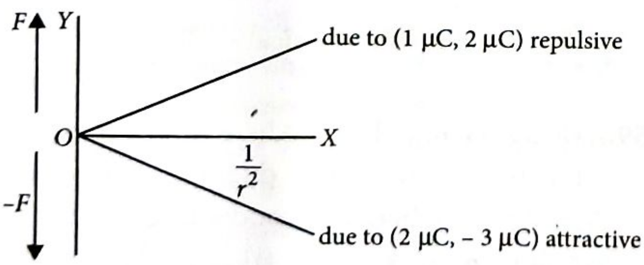
In medium, $F' = \frac{1}{4\pi\varepsilon_0 K}\frac{q^2}{r^2}$

$\therefore \quad F' = \frac{F}{K}$

where $K$ is dielectric constant of material and $K > 1$ for insulators.

Hence, the force is reduced, when a plastic sheet is inserted.

**3.**



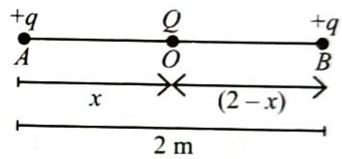

(i) Pair (1 μC, 2 μC) : From upper graph it is clear that the force of repulsion increases with the reducing distance between two charges.

(ii) Pair (2 μC, –3 μC) : From lower graph it is clear that the force of attraction increases as the distance between two charges reduces.

**4.** Let us suppose that the third charge '$Q$' is placed on the line joining the first and second charge such that $AO = x$ and $OB = (2 - x)$.

Net force on each of the three charges must be zero for the system of charges to be in equilibrium.

If we assume that '$Q$' is positive in nature then it will experience forces due to other two charges in opposite direction and the net force on '$Q$' becomes zero. But, the repulsive force acting on either '$q$' will not be zero as the forces acted in same direction.




However, if charge '$Q$' is taken as negative then, on a charge $q$ forces due to other two charges will act in opposite directions. Hence, the third charge must be negative in nature.

For charge $-Q$ to be in equilibrium, the force acting on $-Q$ due to $+q$ at $A$ and $+q$ at $B$ should be equal and opposite.

$$\frac{1}{4\pi\varepsilon_0}\frac{Qq}{x^2} = \frac{1}{4\pi\varepsilon_0}\frac{Qq}{(2-x)^2}$$

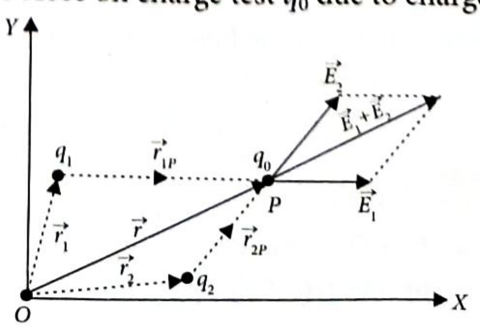
$\Rightarrow \quad x^2 = (2 - x)^2$

$x = \pm (2 - x)$

$x = 1$ m

*i.e.*, the position of third charge is at 1 m from either charge '$q$'.

**5.** Consider a system of $n$ point charges $q_1$, $q_2$, ...., $q_n$ having position vectors $\vec{r}_1, \vec{r}_2, ....., \vec{r}_n$ with respect to the origin $O$. According to Coulomb's law, the force on charge test $q_0$ due to charge $q_1$ is



$$\vec{F}_1 = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_0}{r_1^2} \hat{r}_{1P}$$

where $\hat{r}_{1P}$ is a unit vector in the direction from $q_1$ to $P$ and $r_{1P}$ is the distance between $q_1$ and $P$. Hence the electric field at point $P$ due to charge $q_1$ is

$$\vec{E}_1 = \frac{\vec{F}_1}{q_0} = \frac{1}{4\pi\varepsilon_0} \frac{q_1}{r_{1P}^2} \hat{r}_{1P}$$

Similarly, electric field at $P$ due to charge $q_2$ is

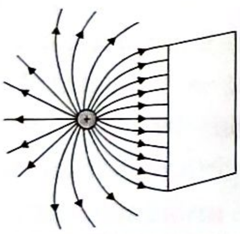
$$\vec{E}_2 = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_2}{r_{2P}^2} \hat{r}_{2P}$$

If $\vec{E}$ is the electric field at point $P$ due to the system of charges, then by the principle of superposition of electric fields,

$$\vec{E} = \vec{E}_1 + \vec{E}_2 + ..... + \vec{E}_n$$

$$= \frac{1}{4\pi\varepsilon_0} \left[ \frac{q_1}{q_2} \hat{r}_{1P} + \frac{q_1}{q_2} \hat{r}_{2P} + ... + \frac{q_n}{r_{nP}^2} \hat{r}_{nP} \right]$$

or $$\vec{E} = \frac{1}{4\pi\varepsilon_0} \sum_{i=1}^{n} \frac{q_i}{r_{iP}^2} \hat{r}_{iP}$$

6. 

7. Electrostatic field lines do not form closed loops due to conservative nature of electric field.

8. At the point of intersection of two field lines, there will be two directions for the resultant electric field. This is not acceptable.

9. *Refer to answer 6.*

10. Electric flux $\Delta\phi = \vec{E} \cdot \Delta\vec{S} = E \, \Delta S \cos\theta$.

11. (i) Electric flux: Total number of electric field lines crossing a surface normally is called electric flux. SI unit of electric flux is N m$^2$ C$^{-1}$.

(ii) The area of a surface can be represented as a vector along normal to the surface.

Here $\vec{E} = 3 \times 10^3 \hat{i}$ NC$^{-1}$

Area of the square $\Delta S = 10 \times 10$ cm$^2$

$\Delta S = 100$ cm$^2 = 10^{-2}$ m$^2$

Since normal to the square is along $x$-axis, we have

$\Delta S = 10^{-2} \hat{i}$ m$^2$

Electric flux through the square,

$\phi = \vec{E} \cdot \Delta\vec{S} = (3 \times 10^3 \hat{i}) \cdot (10^{-2} \hat{i})$

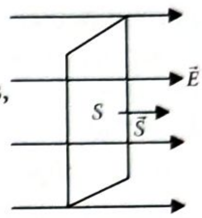
$\phi = 30$ N m$^2$ C$^{-1}$

12. Here, $\vec{E} = 5 \times 10^3 \hat{i}$ N/C

Side of square $= a = 10$ cm $= 0.1$ m

Area of square,

$S = a^2 = (0.1)^2 = 0.01$ m$^2$




Case I : Area vector is along $x$-axis,

$\vec{S} = 0.01 \hat{i}$ m$^2$

Required flux, $\phi = \vec{E} \cdot \vec{S}$

$\Rightarrow \phi = (5 \times 10^3 \hat{i}) \cdot (0.01 \hat{i}) \Rightarrow \phi = 50$ N m$^2$/C

Case II : Plane of the square makes a 30° angle with the $x$-axis.

Here, angle between area vector and the electric field is 60°.

So, required flux $\phi' = E \cdot S \cos\theta$

$= (5 \times 10^3)(10^{-2}) \cos 60° = 25$ N m$^2$/C

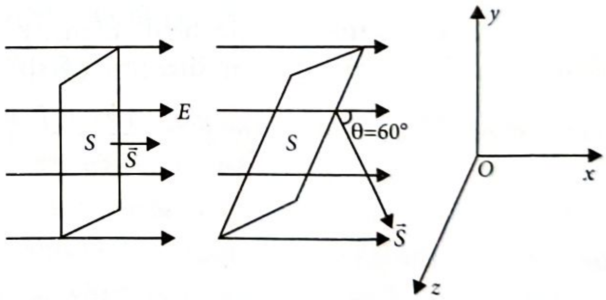
13. Given electric field $\vec{E} = 3 \times 10^3 \hat{i}$ NC$^{-1}$

Magnitude of area, $S = 10$ cm$^2 = 1 \times 10^{-3}$ m$^2$

(i) When the surface is parallel to $y$-$z$ plane, the normal to plane is along $x$-axis.

In this case $\theta = 0$; so electric flux,

$\phi = \vec{E} \cdot \vec{S} = (3 \times 10^3 \hat{i}) \cdot (1 \times 10^{-3} \hat{i}) = 3$ N m$^2$ C$^{-1}$




(ii) In this case $\theta = 60°$, so electric flux,

$\phi = E. \, S \cos\theta$

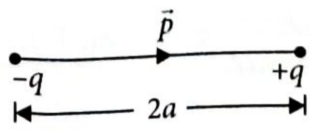
$= 3 \times 10^3 \times 1 \times 10^{-3} \cos 60° = 3 \times \frac{1}{2}$

$= 1.5$ N m$^2$ C$^{-1}$.

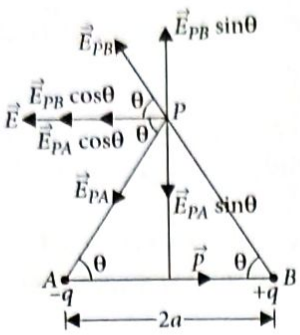
14. Strength of an electric dipole is measured by its electric dipole moment, whose magnitude is equal to product of magnitude of either charge and separation between the two charges *i.e.*,

$\vec{p} = q \cdot (2\vec{a})$

and is directed from negative to positive charge, along the line joining the two charges. Its SI unit is C m.



**15.** Electric field on the equatorial line of an electric dipole : Electric field at any point on the perpendicular bisector of an electric dipole at distance $r$ from its centre is




$$E_{net} = E_x = E_{PA}\cos\theta + E_{PB}\cos\theta$$

(Vertical component cancel each other)

or $E_{net} = 2E_{PA}\cos\theta \qquad (E_{PA} = E_{PB})$

$$E_{net} = 2\cdot\frac{1}{4\pi\varepsilon_0}\frac{q}{(r^2+a^2)}\cdot\frac{a}{(r^2+a^2)^{1/2}}$$

$$E_{net} = \frac{1}{4\pi\varepsilon_0}\frac{q\cdot 2a}{(r^2+a^2)^{3/2}}$$

or $E_{net} = \dfrac{1}{4\pi\varepsilon_0}\dfrac{p}{(r^2+a^2)^{3/2}}$

directed antiparallel to dipole moment $\vec{p}$. For short dipole, when $r >>> a$, then electric field at point $P$ is

$$E = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}$$

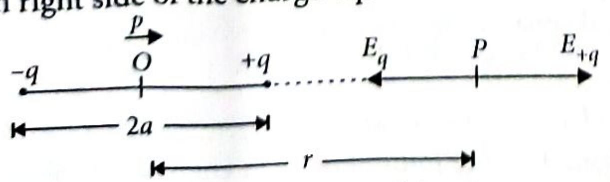
In vectorial form, the electric field intensity at point $P$ on the perpendicular bisector of short electric dipole is then given by $\vec{E} = \dfrac{1}{4\pi\varepsilon_0}\dfrac{-\vec{p}}{r^3}\cdot\hat{r}$

**16.** *Refer to answer 15.*

**17.** *Refer to answer 15.*

**18.** (a) Electric field at an axial point of an electric dipole.

Let us consider an electric dipole consisting of charges $+q$ and $-q$, seperated by distance $2a$ and placed in vacuum. Let $P$ be a point on the axial line at distance $r$ from the centre $O$ of the dipole on right side of the charge $+q$.




Electric field at an axial point of dipole

$$\vec{E}_{-q} = \frac{-q}{4\pi\varepsilon_0(r+a)^2}\hat{p} \quad \text{(towards left)}$$

where $\hat{p}$ is a unit vector along the dipole axis from $-q$ to $+q$.

Electric field due to charge $+q$ at point $P$ is

$$\vec{E}_{+q} = \frac{q}{4\pi\varepsilon_0(r-a)^2}\hat{p} \quad \text{(towards right)}$$

Hence the resultant electric field at point $P$ is

$$\vec{E}_{axial} = \vec{E}_{+q} + \vec{E}_{-q} = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{(r-a)^2} - \frac{1}{(r+a)^2}\right]\hat{p}$$

$$= \frac{q}{4\pi\varepsilon_0}\cdot\frac{4ar}{(r^2-a^2)^2}\hat{p}$$

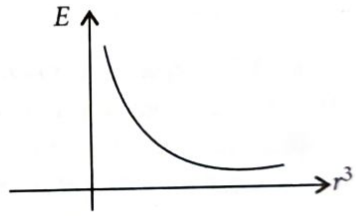
or $\vec{E}_{axial} = \dfrac{1}{4\pi\varepsilon_0}\cdot\dfrac{2pr}{(r^2-a^2)^2}\hat{p}$

Here $p = q \times 2a$ = dipole moment

For $r >> a$, $a^2$ can be neglected as compared to $r^2$.

or $\vec{E}_{axial} = \dfrac{1}{4\pi\varepsilon_0}\cdot\dfrac{2p}{r^3}\hat{p}$ (towards right)

(b)




**19.** *Refer to answer 18 (a).*

**20.** *Refer to answer 15.*

**21.** *Refer to answers 14 and 15.*

**22.** The torque $\vec{\tau}$ acting on a dipole of dipole moment $\vec{p}$ placed in an electric field $\vec{E}$ is given by

$\vec{\tau} = \vec{p}\times\vec{E}$

$\tau = pE\sin\theta$

where $\theta$ = Angle between dipole moment and electric field.

**23.** Work done in rotating the dipole through an angle $\theta$ in uniform electric field, $U = -pE\cos\theta$.

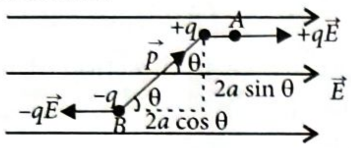
When $\theta = 0°$, then $U_{min} = -pE$

So, potential energy of an electric dipole is minimum, when it is placed with its dipole moment $\vec{p}$ parallel to the direction of electric field $\vec{E}$ and so it is called its most stable equilibrium position.

When $\theta = 180°$, then $U_{max} = +pE$

So, potential energy of an electric dipole is maximum, when it is placed with its dipole moment $\vec{p}$ anti parallel to the direction of electric field $\vec{E}$ and so it is called its most unstable equilibrium position.

**24.** (i) Torque on a dipole in uniform electric field: When electric dipole is placed in a uniform electric field, its two charges experience equal and opposite forces, which cancel each other and hence net force on an electric dipole in a uniform electric field is zero.




However these forces are not collinear, so they give rise to some torque on the dipole given by

Torque = Magnitude of either force

× Perpendicular distance between them

$\tau = Fr_{\perp} = qE.2a \sin\theta = q2a.\, E \sin\theta$

or $\tau = pE \sin\theta$

where θ is the angle between the directions of $\vec{P}$ and $\vec{E}$.

In vectorial form, $\vec{\tau} = \vec{p} \times \vec{E}$

(a) When $\theta = 0°$ or $180°$ then $\tau_{min} = 0$

(b) When $\theta = 90°$ then $\tau_{max} = pE$

Thus, torque on a dipole tends to align it in the direction of uniform electric field.

(ii) If the field is not uniform in that condition the net force on electric dipole is not zero.

**25.** *Refer to answer 24 (i).*

$\vec{\tau} = \vec{p} \times \vec{E}$

Pairs of perpendicular vectors

(a) $(\vec{\tau}, \vec{p})$ (b) $(\vec{\tau}, \vec{E})$

**26.** *Refer to answer 24 (i).*

(i) When $\theta = 0$; $\tau = 0$ and $\vec{p}$ and $\vec{E}$ are parallel and the dipole is in a position of stable equilibrium.

(ii) When $\theta = 180°$, $\tau = 0$ and $\vec{p}$ and $\vec{E}$ are antiparallel and the dipole is in a position of unstable equilibrium.

**27.** *Refer to answer 24 (i).*

**28.** (a) Suppose an electric dipole of dipole moment $\vec{p}$ is placed along a direction, making an angle θ with the direction of an external uniform electric field $\vec{E}$. Then, the torque acting on the dipole is defined as $pE \sin\theta$ or $\vec{\tau} = \vec{p} \times \vec{E}$.

Its direction will be perpendicular to both $\vec{p}$ and $\vec{E}$.

(b)If the field is non-uniform there would be a net force on the dipole in addition to the torque and the resulting motion would be a combination of translation and rotation.

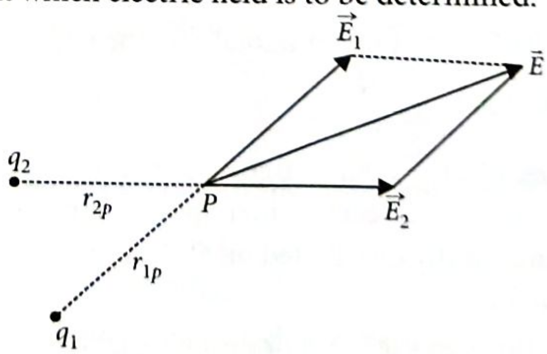
If the field is non-uniform there would be a net force on the dipole in addition to the torque and the resulting motion would be a combination of translation and rotation.

(c) (i) $\vec{E}$ is increasing parallel to $\vec{p}$ then $\theta = 0°$. So torque becomes zero but the net force on the dipole will be in the direction of increasing electric field and hence it will have linear motion along the dipole moment.

(ii) $\vec{E}$ is increasing anti-parallel to $\vec{p}$. So, the torque still remains zero but the net force on the dipole will be in the direction of increasing electric field which is opposite to the dipole moment, hence it will have linear motion opposite to the dipole moment.

**29.** *Refer to answer 24 (i).*

**30.** Electric field due to a system of charges : Consider a system of charges $q_1$ and $q_2$ with position vectors $\vec{r}_1$ and $\vec{r}_2$ relative to common origin *O*. Let *P* be any point with position vector $\vec{r}$ at which electric field is to be determined.




Electric field $\vec{E}_1$ due to $q_1$ is given by

$$\vec{E}_1 = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1}{r_{1p}^2} \hat{r}_{1p}$$

where $\hat{r}_{1p}$ is a unit vector in the direction from $q_1$ to *P* and $r_{1p}$ is the distance between $q_1$ and *P*.

Similarly, electric field $\vec{E}_2$ due to $q_2$ is

$$\vec{E}_2 = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_2}{r_{2p}^2} \cdot \hat{r}_{2p}$$

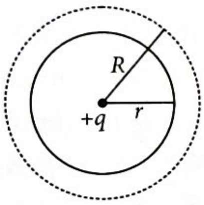
where $\hat{r}_{2p}$ is a unit vector in the direction from $q_2$ to $P$ and $r_{2p}$ is the distance between $q_2$ and $P$.

By the superposition principle, the electric field $\vec{E}$ at $\vec{r}$ due to the system of charges is $\vec{E}(r) = \vec{E}_1(r) + \vec{E}_2(r)$

$$= \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1}{r_{1p}^2} \cdot \hat{r}_{1p} + \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_2}{r_{2p}^2} \cdot \hat{r}_{2p}$$

$$\therefore \quad \vec{E}(r) = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1}{r_{1p}^2}\hat{r}_{1p} + \frac{q_2}{r_{2p}^2}\hat{r}_{2p}\right]$$

**31.** According to Gauss's law, theelectric flux passing through a closed surface is given by




$$\oint \vec{E} \cdot d\vec{s} = \frac{q_{\text{enclosed}}}{\varepsilon_0}$$

When radius of spherical Gaussian surface is increased, its surface area will be increased but point charge enclosed in the sphere remains same. Hence there will be no change in the electric flux.

**32.** According to Gauss's law, net flux through a closed surface, $\phi_E = \oint \vec{E} \cdot d\vec{s} = \frac{q_{en}}{\varepsilon_0}$

Total charge enclosed, $q_{en} = 0$

as net charge on dipole is zero.

$$\therefore \quad \phi_E = \frac{0}{\varepsilon_0} = 0$$

**33.** By Gauss's theorem, total flux through whole of the cube, $\phi = \frac{q}{\varepsilon_0}$

where, $q$ is the total charge enclosed by the cube. As, charge is at centre, therefore, electric flux is symmetrically distributed on all 6 faces.

Therefore,

Flux through each face of the cube, $\phi' = \frac{\phi}{6} = \frac{q}{6\varepsilon_0}$

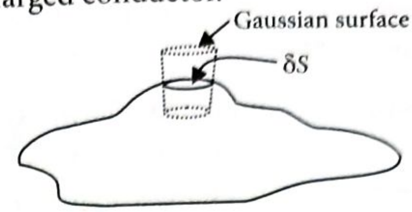
**34.** Total charge within a surface $S$

$= +2q + (-q) = +q$

$\therefore$ Electric flux $\phi = \frac{q}{\varepsilon_0}$

**35.** *Refer to answer 33.*

**36.** Consider an elementary area $\delta S$ on the surface of the charged conductor.




Enclose this area element with a cylindrical gaussian surface as shown in figure.

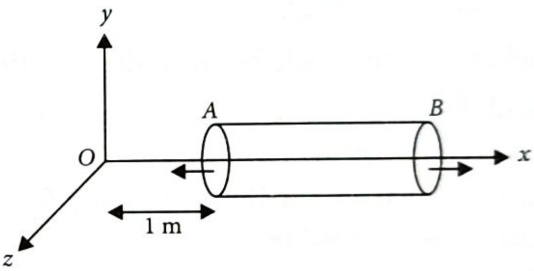
Now electric field inside a charged conductor is zero. Therefore, direction of field, just outside $\delta S$ will be normally outward *i.e.* in direction of $\hat{n}$.

According to Gauss's theorem, total electric flux coming out is

$$\vec{E} \cdot \delta\vec{S} = \frac{\sigma\,\delta S}{\varepsilon_0} \quad [\vec{E} \text{ is electric field at the surface}]$$

$$\Rightarrow \quad E\,\delta S \cos 0° = \frac{\sigma\,\delta S}{\varepsilon_0} \Rightarrow E = \frac{\sigma}{\varepsilon_0}$$

**37.** (i)




Given, $\vec{E} = 50x\hat{i}$ and $A = 25\text{ cm}^2 = 25 \times 10^{-4}\text{ m}^2$

As the electric field is only along the $x$-axis, so, flux will pass only through the cross-section of cylinder.

Magnitude of electric field at cross-section $A$,

$E_A = 50 \times 1 = 50\text{ N C}^{-1}$

Magnitude of electric field at cross-section $B$,

$E_B = 50 \times 2 = 100\text{ N C}^{-1}$

The corresponding electric fluxes are

$\phi_A = \vec{E}_A \cdot \vec{A} = 50 \times 25 \times 10^{-4} \cos 180°$

$= -0.125\text{ N m}^2\text{ C}^{-1}$

$\phi_B = \vec{E}_B \cdot \vec{A} = 100 \times 25 \times 10^{-4} \cos 0°$

$= 0.25\text{ N m}^2\text{ C}^{-1}$

So, the net flux through the cylinder,

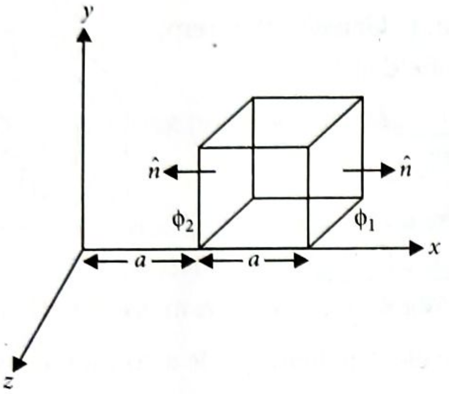
$\phi = \phi_A + \phi_B = -0.125 + 0.25 = 0.125\text{ N m}^2\text{ C}^{-1}$

(ii) Using Gauss's law

$$\oint \vec{E} \cdot d\vec{A} = \frac{q}{\varepsilon_0} \Rightarrow 0.125 = \frac{q}{8.85 \times 10^{-12}}$$

$$\Rightarrow \quad q = 8.85 \times 0.125 \times 10^{-12} = 1.1 \times 10^{-12}\text{ C}$$

**38.** Gauss's law in electrostatics states that the total electric flux through a closed surface enclosing a charge is equal to $\frac{1}{\varepsilon_0}$ times the magnitude of that charge.




$$\phi = \oint \vec{E} \cdot \vec{dS} = \frac{q}{\varepsilon_0}$$

(i) Net flux, $\phi = \phi_1 + \phi_2$

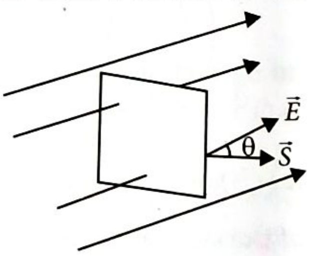
where $\phi_1 = 2aC\, dS \cos 0° = 2aC \times a^2 = 2a^3C$

$\phi_2 = aC \times a^2 \cos 180° = -a^3C$

$\phi = 2a^3C + (-a^3C) = a^3C \text{ Nm}^2 \text{ C}^{-1}$

(ii) Net charge $(q) = \varepsilon_0 \times \phi = a^3C\, \varepsilon_0$ coulomb

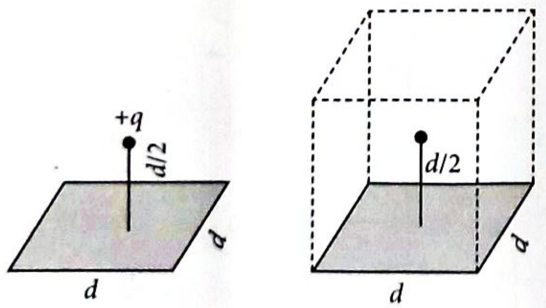
**39.** (a) Electric flux linked with a surface is the number of electric lines of force cutting through a surface normally and is measured as surface integral of electric field over that surface $S$ *i.e.*,




$$\phi = \int_s \vec{E} \cdot d\vec{S}$$

It is a scalar quantity

Let us assume that the given square be one face of the cube of edge $d$ cm. As charge of $q$ is at distance of $d/2$ above the centre of a square, so it is enclosed by the cube. Hence by Gauss's theorem, electric flux linked with the cube is




$$\phi = \frac{q}{\varepsilon_0}$$

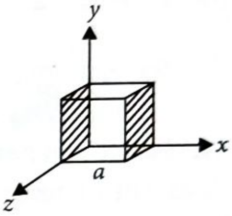
So, the magnitude of the electric flux through the square is

$$\phi_{sq} = \frac{\phi}{6} = \frac{q}{6\varepsilon_0}$$

(b) Here distance of point charge becomes doubled and also sides of square gets doubled. Same kind of symmetry is still here with sides of cube $2d$, hence electric flux through the square will not be affected *i.e.*, $\phi_{sq} = \frac{q}{6\varepsilon_0}$.

Hence there will be no change in electric flux.

**40.** $\vec{E} = 2x\hat{i}$




So, flux passes through faces of cube which are perpendicular to $x$-axis.

The magnitude of electric field at the left face ($x = 0$), $E_L = 0$

The magnitude of electric field at the right face, ($x = a$), $E_R = 2a$

So, net flux, $\phi = \vec{E} \cdot \Delta\vec{s}$

$= E_L \Delta s \cos 180° + E_R \Delta s \cos 0°$

$= 0 + 2a \times a^2 = 2a^3$

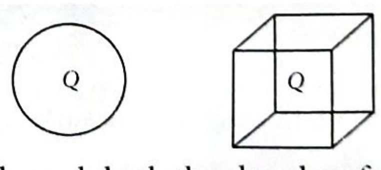
Assume enclosed charge is $q$.

Use Gauss's law, $\phi = \frac{q}{\varepsilon_0}$; $q = \varepsilon_0 \phi$ $\therefore$ $q = 2a^3\varepsilon_0$

**41.** Electric flux linked with a surface is the number of electric lines of force cutting through the surface normally.

It's SI unit is $\text{N m}^2 \text{ C}^{-1}$ or V m. On decreasing the radius of spherical surface to half there will be no effect on the electric flux.

Let us take a charge Q inside a cube or a sphere.




The flux through both the closed surfaces will be same. *i.e.*, $\phi_{net} = \frac{Q}{\varepsilon_0}$

**42.** (i) Charge enclosed by sphere $S_1 = 2Q$

By Gauss law, electric flux through sphere $S_1$ is

$\phi_1 = 2Q/\varepsilon_0$

Charge enclosed by sphere,

$S_2 = 2Q + 4Q = 6Q$

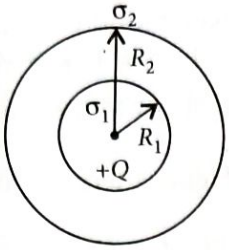
$\phi_2 = 6Q/\varepsilon_0$

The ratio of the electric flux is

$\phi_1 : \phi_2 = 2 : 6 = 1 : 3$

(ii) When a medium of dielectric constant $\varepsilon_r$ is introduced in sphere $S_1$, the flux through $S_1$ would be $\phi_1' = \dfrac{2Q}{\varepsilon_0 \varepsilon_r}$

**43.** (i) Charge induced on the inner surface = $-Q$



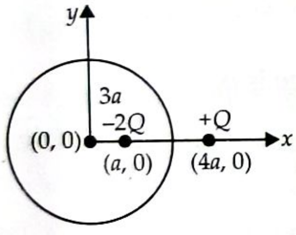

$\therefore \quad \sigma_1 = \dfrac{-Q}{4\pi R_1^2}$

(ii) Charge induced on the outer surface = $+Q$

$\therefore \quad \sigma_2 = \dfrac{Q}{4\pi R_2^2}$

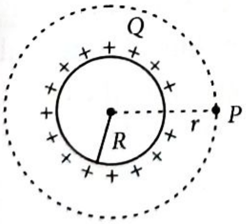
**44.** No, the charge given to a metallic sphere does not depend on whether it is hollow or solid because all the charges will move to the outer surface of the sphere. Charge will be distributed uniformly over the surface of the sphere.

**45.**




Electric flux $\phi = \dfrac{q_{\text{inside}}}{\varepsilon_0} = \dfrac{-2Q}{\varepsilon_0}$

**46.** Using Gauss's theorem at point $P$,




$$\oint \vec{E} \cdot d\vec{s} = \frac{Q}{\varepsilon_0}$$

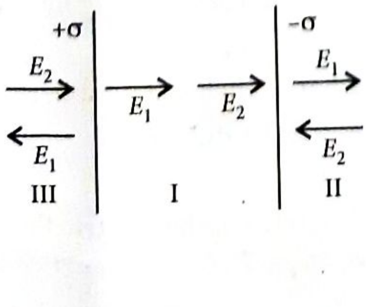
$$\int E\, 4\pi r^2 \cos 0° = \frac{Q}{\varepsilon_0}$$

($\because$ $E$ is constant throughout the surface)

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

This is same as electric field due to a point charge which can be assumed to be concentrated at the centre.

**47.** The direction of electric field in various regions is given as follows :

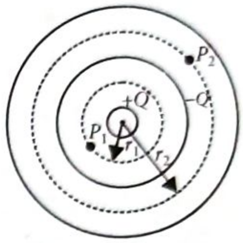



$$E_1 = E_2 = \frac{\sigma}{2\varepsilon_0}$$

(i) $E_{\text{net}} = |\vec{E_1} + \vec{E_2}| = \dfrac{\sigma}{2\varepsilon_0} + \dfrac{\sigma}{2\varepsilon_0} = \dfrac{\sigma}{\varepsilon_0}$

(ii) $E_{\text{net}} = E_1 - E_2 = \dfrac{\sigma}{2\varepsilon_0} - \dfrac{\sigma}{2\varepsilon_0} = 0$

**48.** Using Gauss's theorem, electric field at $P_1$




$$E_1 = \frac{1}{4\pi\varepsilon_0} \frac{Q}{r_1^2}$$

Again field at $P_2$,

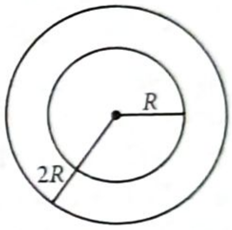
$$E_2 = \frac{1}{4\pi\varepsilon_0} \frac{Q}{r_2^2} = 0$$

Because electric field inside a conductor is zero.

**49.** Surface charge density, $\sigma$ = constant

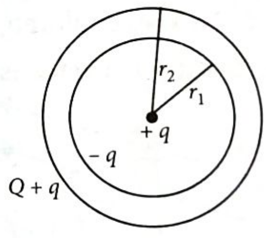
Charge $Q_1 = 4\pi R^2 \sigma$

Charge $Q_2 = 4\pi (2R)^2 \sigma$




$$\therefore \quad \frac{Q_1}{Q_2} = \frac{4\pi R^2 \sigma}{4\pi (2R)^2 \sigma} = \frac{1}{4}$$

**50.**

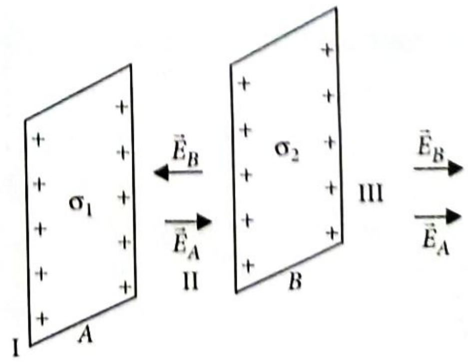



(a) (i) Surface charge density on the inner surface of the shell is $\sigma_{\text{in}} = \dfrac{-q}{4\pi r_1^2}$

(ii) Surface charge density on the outer surface of shell is $\sigma_{\text{out}} = \dfrac{Q+q}{4\pi r_2^2}$

(b) Using, Gauss's law, $E(x) = \dfrac{1}{4\pi\varepsilon_0} \dfrac{Q+q}{x^2}$

**51.**




In region II :

The electric field due to the sheet of charge $A$ will be from left to right (along the positive direction) and that due to the sheet of charge $B$ will be from right to left (along the negative direction). Therefore, in region II, we have

$$E=\frac{\sigma_1}{\varepsilon_0}+\left(-\frac{\sigma_2}{\varepsilon_0}\right)$$

$$\vec{E}=\frac{1}{\varepsilon_0}(\sigma_1-\sigma_2) \text{ along positive direction}$$

In region III :

The electric fields due to both the charged sheets will be from left to right, *i.e.*, along the positive direction. Therefore, in region III, we have

$$E=\frac{\sigma_1}{\varepsilon_0}+\frac{\sigma_2}{\varepsilon_0}$$

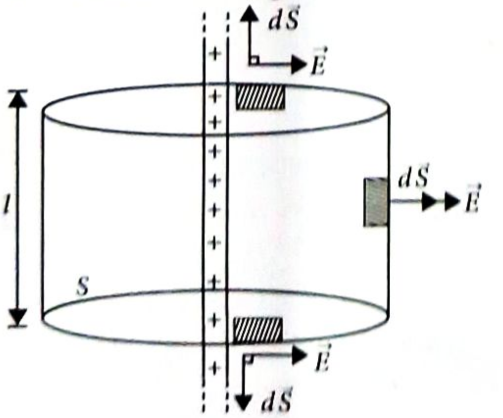
$$\vec{E}=\frac{1}{\varepsilon_0}(\sigma_1+\sigma_2) \text{ along positive direction}$$

**52.** (i) According to Gauss's law, total flux over a closed surface $S$ in vacuum is $\frac{1}{\varepsilon_0}$ times the total charge enclosed by closed surface $S$

$$\phi=\oint_s \vec{E}\cdot\vec{ds}=\frac{q_{\text{enclosed}}}{\varepsilon_0}$$

(ii) Electric field intensity due to line charge or infinite long uniformly charged wire at point $P$ at distance $r$ from it is obtained as :

Assume a cylindrical gaussian surface $S$ with charged wire on its axis and point $P$ on its surface, then net electric flux through surface $S$ is




$$\phi=\oint_S \vec{E}\cdot d\vec{S}=\underset{\substack{\text{upper}\\\text{plane}\\\text{face}}}{\int EdS\cos 90^\circ}+\underset{\substack{\text{curved}\\\text{surface}}}{\int EdS\cos 0^\circ}+\underset{\substack{\text{lower}\\\text{plane}\\\text{face}}}{\int EdS\cos 90^\circ}$$

or $\phi = 0 + EA + 0$ or $\phi = E.2\pi rl$

But by Gauss's theorem $\phi=\frac{q}{\varepsilon_0}=\frac{\lambda l}{\varepsilon_0}$

Where $q$ is the charge on length $l$ of wire enclosed by cylindrical surface $S$, and $\lambda$ is uniform linear charge density of wire.

$$\therefore\quad E\times 2\pi rl=\frac{\lambda l}{\varepsilon_0} \text{ or } E=\frac{\lambda}{2\pi\varepsilon_0 r}$$

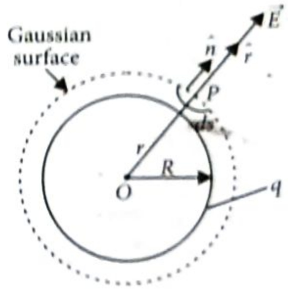
directed normal to the surface of charged wire.

**53.** Consider a thin spherical shell of radius $R$ carrying charge $q$. To find the electric field outside the shell, we consider a spherical Gaussian surface of radius $r$ ($> R$), concentric with given shell.

The electric field $\vec{E}$ is same at every point of Gaussian surface and directed radially outwards (as is unit vector $\hat{n}$ so that $\theta = 0°$)

According to Gauss's theorem,

$$\oint_s \vec{E}\cdot\vec{ds}=\oint_s \vec{E}\cdot\hat{n}\,ds=\frac{q}{\varepsilon_0}$$




$$\text{or}\quad E\oint_s ds=\frac{q}{\varepsilon_0}$$

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

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

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

Special cases

(i) At the point on the surface of the shell, $r = R$

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

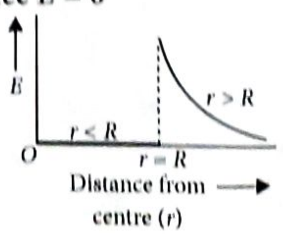
(ii) If $\sigma$ is the surface charge density on the shell then $q = 4\pi R^2\sigma$

$$\therefore\quad E=\frac{1}{4\pi\varepsilon_0}\cdot\frac{4\pi R^2\sigma}{R^2}=\frac{\sigma}{\varepsilon_0}$$

(iii) If the point $P$ lies inside the spherical shell then the Gaussian surface encloses no charge

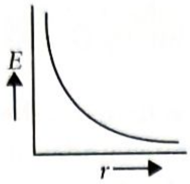
*i.e.*, $r < R$

$\because\quad q = 0$, hence $E = 0$



**54.** (a) *Refer to answer 52 (ii).*

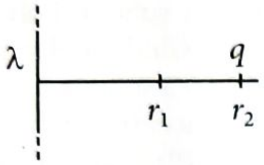
(b) Since $E = \dfrac{\lambda}{2\pi\varepsilon_0 r} \Rightarrow E \propto \dfrac{1}{r}$




Therefore plot of $E$ versus $r$ will be as shown.

(c) As per the situation charge $q$ is kept at a distance $r_2$ from line charge.

$$E_{(r_2)} = \frac{\lambda}{2\pi\varepsilon_0 r_2} \text{ and } E'_{(r_1)} = \frac{\lambda}{2\pi\varepsilon_0 r_1}$$



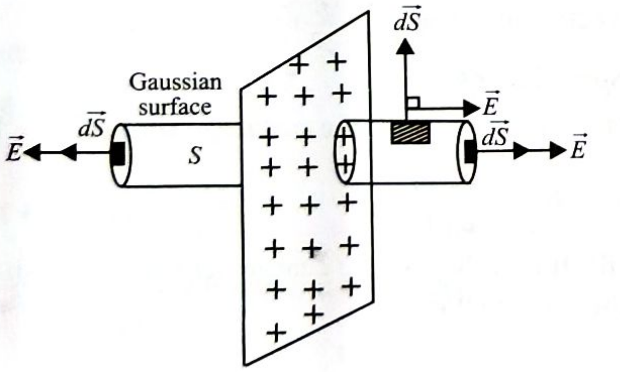

Work done in moving charge $q$ form $r_2$ to $r_1$.

$$W = \int_{r_2}^{r_1} \vec{F} \cdot d\vec{r}$$

$$= \int_{r_2}^{r_1} \frac{q\lambda}{2\pi\varepsilon_0 r} dr \cos 0° = \frac{q\lambda}{2\pi\varepsilon_0} \int_{r_2}^{r_1} \frac{dr}{r}$$

$$= \frac{q\lambda}{2\pi\varepsilon_0} \left[\ln r\right]_{r_2}^{r_1} = \frac{q\lambda}{2\pi\varepsilon_0} \ln \frac{r_1}{r_2}$$

**55.** Assume a cylindrical Gaussian surface $S$ cutting through plane sheet of charge, such that point $P$ lies on its plane face, then net electric flux through surface $S$ is




$$\phi = \oint_S \vec{E} \cdot d\vec{s} = \int_{\substack{\text{left}\\\text{plane}\\\text{face}}} \vec{E} \cdot d\vec{s} + \int_{\substack{\text{curved}\\\text{surface}}} \vec{E} \cdot d\vec{s} + \int_{\substack{\text{right}\\\text{plane}\\\text{face}}} \vec{E} \cdot d\vec{s}$$

$$\text{or } \phi = \int_{\substack{\text{left}\\\text{plane face}}} Eds \cos 0° + \int_{\substack{\text{curved}\\\text{surface}}} Eds \cos 90° + \int_{\substack{\text{right}\\\text{plane face}}} Eds \cos 0°$$

or $\phi = EA + 0 + EA = 2EA$

But by Gauss's theorem $\phi = \dfrac{q}{\varepsilon_0} = \dfrac{\sigma A}{\varepsilon_0}$

where $q$ is the charge in area $A$ of sheet enclosed by cylindrical surface $S$ and $\sigma$ is uniform surface charge density of sheet.

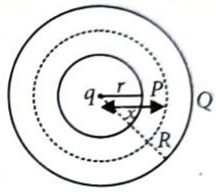
$\therefore \quad 2EA = \dfrac{\sigma A}{\varepsilon_0}$ or $E = \dfrac{\sigma}{2\varepsilon_0}$

directed normal to surface of charged sheet (i) away from it, if it is positively charged and (ii) towards it, if it is negatively charged.

**56.** *Refer to answer 55.*

**57.** *Refer to answer 53.*

**58.** (i) Consider a sphere of radius $r$ with centre $O$ surrounded by a large concentric conducting shell of radius $R$.




To calculate the electric field intensity at any point $P$, where $OP = x$, imagine a Gaussian surface with centre $O$ and radius $x$, as shown in the figure.

The total electric flux through the Gaussian surface is given by

$$\phi = \oint Eds = E\oint ds$$

Now, $\oint ds = 4\pi x^2$

$\therefore \quad \phi = E \times 4\pi x^2$ ...(i)

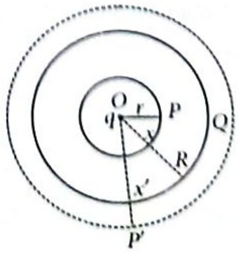
Since the charge enclosed by the Gaussian surface is $q$, according to Gauss's theorem,

$\phi = \dfrac{q}{\varepsilon_0}$ ...(ii)

From (i) and (ii), we get

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

(ii) To calculate the electric field intensity at any point $P'$, where point $P'$ lies outside the spherical shell, imagine a Gaussian surface with centre $O$ and radius $x'$, as shown in the figure



According to Gauss's theorem,

$$E'(4\pi x'^2) = \frac{q+Q}{\varepsilon_0}$$

$$\Rightarrow \quad E' = \frac{q+Q}{4\pi\varepsilon_0 x'^2}$$

As the charge always resides only on the outer surface of a conduction shell, the charge flows essentially from the sphere to the shell when they are connected by a wire. It does not depend on the magnitude and sign of charge Q.

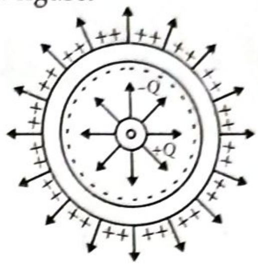
**59.** *Refer to answer 53.*

**60.** *Refer to answer 53.*

**61.** (i) *Refer to answer 41.*

(ii) *Refer to answer 48.*

(iii) The electric field lines due to the arrangement is shown in the figure.




Charges will be uniformly distributed on the whole surfaces hence, all field lines will be uniformly separated.