# Important Questions for Class 12

# Physics

# Chapter 1 – Electric charges and fields

**Very Short Answer Questions** **1 Mark**

**1. Does the force between two point charges change if the dielectric constant of the medium in which they are kept is increased?**

**Ans:** Dielectric constant of a medium is given by

$$k=\frac{F_V}{F_M}=\frac{\text{force between the charges in vaccum}}{\text{force between two charges in medium}}$$

$$\Rightarrow F_M=\frac{F_V}{k}$$

From the above expression, it is clear that as $k$ is increased, $F_M$ gets decreased.

**2. A charged rod $P$ attracts a rod $R$ whereas $P$ repels another charged rod $Q$. What type of force is developed between $Q$ and $R$?**

**Ans:** Suppose that the rod $P$ is negatively charged. As it attracts rod $R$, it can be said that $R$ is positively charged.

Also, since $P$ repels rod $Q$, it can be said that $Q$ is negatively charged.

Clearly, the force between $Q$ and $R$ would be attractive in nature.

**3. Which physical quantity has its S.I. unit**

1. $Cm$ ?
2. $N/C$ ?

**Ans: 1.** The S.I. unit of electric dipole moment is $Cm$.

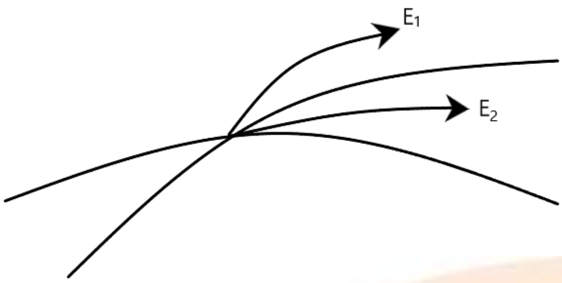
2. The S.I. unit of electric field intensity is $N/C$.

**4. Define one coulomb.**

**Ans:** Charge on a body is said to be $1$ coulomb if it experiences a force of repulsion or attraction of $9\times10^9 N$ from another equal charge when they are separated by a distance of $1m$.

**Short Answer Questions** **2 Marks**

**1. A free proton and a free electron are placed in a uniform field. Which of the two experiences greater force and greater acceleration?**

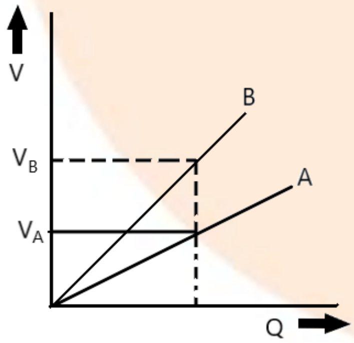



**Ans:** Force on both the electron as well as the proton in the uniform field would be equal because $F = kq$ and it is known that charge on both electron and proton are the same. On the other hand, since acceleration is given by $a = \frac{F}{m}$ and as the mass of a proton is more than that of an electron, the acceleration of the electron would be more.

**2. No two electric lines of force can intersect each other. Why?**

**Ans:** Two electric lines of force can never intersect each other.
Suppose if they intersect, then at the point of intersection, there can be two tangents drawn.
These two tangents are supposed to represent two directions of electric field lines, which is not possible at a particular point.

**3. The graph shows the variation of voltage $V$ across the plates of two capacitors $A$ and $B$ versus increase of charge $Q$ stored on them. Which of the two capacitors have higher capacitance? Give reason for your answer.**




**Ans:**

It is known that $C = \frac{Q}{V}$

Clearly, for a given charge $Q$,

$C \propto \frac{1}{V}$

Now, from the given graph, it is seen that $V_A < V_B$.

Therefore, it can be concluded that $C_A > C_B$.

**4. An electric dipole when held at $30°$ with respect to a uniform electric field of $10^4 N/C$ experiences a torque of $9\times10^{-26}Nm$. Calculate dipole moment of the dipole?**

**Ans:** It is given that

$\theta = 30°$

$\tau = 9\times10^{-26}Nm$

$E = 10^4 N/C$

Dipole moment $P$ needs to be calculated.

It is known that torque is given by $\tau = PE\sin\theta$.

Clearly,

$$\Rightarrow P = \frac{\tau}{E\sin\theta}$$

$$\Rightarrow P = \frac{9\times10^{-26}}{10^4\times\sin30°} = \frac{9\times10^{-26}\times10^{-4}\times2}{1}$$

$$\Rightarrow P = 18\times10^{-30}Cm$$

**5.**

**a) Explain the meaning of the statement 'electric charge of a body is quantized'.**

**Ans:** The statement 'electric charge of a body is quantized' suggests that only integral $(1, 2, 3, 4, \ldots, n)$ number of electrons can be transferred from one body to another.

This further suggests that charges are not transferred in fractions.

Hence, a body possesses its total charge only in integral multiples of electric charges.

**b) Why can one ignore the quantization of electric charge when dealing with macroscopic i.e., large scale charge?**

**Ans:** When dealing with macroscopic or large-scale charges, the charges used are huge in number as compared to the magnitude of electric charge.

Hence, the quantization of electric charge is of no use on a macroscopic scale.

Therefore, it is ignored and considered that electric charge is continuous.

**6. When a glass rod is rubbed with a silk cloth, charges appear on both. A similar phenomenon is observed with many other pairs of bodies. Explain how this observation is consistent with the law of conservation of charge.**

**Ans:** Rubbing is a phenomenon in which there is production of charges equal in

magnitude but opposite in nature on the two bodies which are rubbed with each other.
It is also seen that during such a phenomenon, charges are created in pairs. This phenomenon of charging is called as charging by friction.
The net charge on a system of two rubbed bodies is equal to zero. This is because equal number of opposite charges in both the bodies annihilate each other.
Clearly, when a glass rod is rubbed with a silk cloth, opposite natured charges appear on both these bodies.
Thus, this phenomenon is consistent with the law of conservation of energy. As already mentioned, a similar phenomenon is observed with many other pairs of bodies too.

**7.**

**a) An electric field line is a continuous curve. That is, a field line cannot have sudden breaks. Why not?**

**Ans:** An electrostatic field line is a continuous curve as it is known that a charge experiences a continuous force when traced in an electrostatic field.
Also, the field line cannot have sudden breaks because the charge moves continuously and does not have the potential to jump from one point to another.

**b) Explain why two field lines never cross each other at any point?**

**Ans:** Suppose two field lines cross each other at a particular point, then electric field intensity will show two directions at that point of intersection.
This is impossible. Thus, two field lines can never cross each other.

**8. An electric dipole with dipole moment $4\times10^{-9}$Cm is aligned at $30°$ with direction of a uniform electric field of magnitude $5\times10^{4}NC^{-1}$. Calculate the magnitude of the torque acting on the dipole.**

**Ans:** It is given that:
Electric dipole moment, $p=4\times10^{-9}Cm$
Angle made by $p$ with uniform electric field, $\theta=30°$
Electric field, $E=5\times10^{4}NC^{-1}$
Torque acting on the dipole is given by $\tau=pE\sin\theta$.

$\Rightarrow\tau=4\times10^{-9}\times5\times10^{4}\times\sin30°$

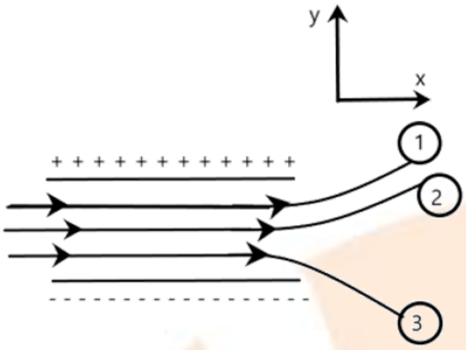
$\Rightarrow\tau=20\times10^{-5}\times\frac{1}{2}$

$\Rightarrow\tau=10^{-4}Nm$

Thus, the magnitude of the torque acting on the dipole is $10^{-4}Nm$.

**9. Figure below shows tracks of three charged particles in a uniform**

**electrostatic field. Give the signs of the three charges. Which particle has the highest charge to mass ratio?**




**Ans:** Since unlike charges attract and like charges repel each other, the particles 1 and 2 moving towards the positively charged plate are negatively charged whereas the particle 3 that moves towards the negatively charged plate is positively charged.
Since the charge to mass ratio is directly proportional to the amount of deflection for a given velocity, particle 3 would have the highest charge to mass ratio.

**10. What is the net flux of the uniform electric field of exercise 1.15 through a cube of side 20cm oriented so that its faces are parallel to the coordinate planes?**
**Ans:** It is given that all the faces of the cube are parallel to the coordinate planes. Clearly, the number of field lines entering the cube is equal to the number of field lines entering out of the cube.
As a result, the net flux through the cube can be calculated to be zero.

**11. Careful measurement of the electric field at the surface of a black box indicate that the net outward flux through the surface of the box is $8.0\times10^{3}Nm^{2}/C$.**

**a) What is the net charge inside the box?**

**Ans:** It is given that:
Net outward flux through surface of the box, $\phi=8.0\times10^{3}Nm^{2}/C$.
For a body containing net charge $q$, flux is given by $\phi=\frac{q}{\varepsilon_0}$,
where,
$\varepsilon_0$ = Permittivity of free space $=8.854\times10^{-12}N^{-1}C^{2}m^{-2}$
Therefore, the charge $q$ is given by $q=\phi\varepsilon_0$.

$\Rightarrow q=8.854\times10^{-12}\times8.0\times10^{3}$
$\Rightarrow q=7.08\times10^{-8}$
$\Rightarrow q=0.07\mu C$

Therefore, the net charge inside the box is $0.07\mu C$.

**b) If the net outward flux through the surface of the box were zero, could you conclude that there were no charges inside the box? Why or why not?**

**Ans:** No.

The net flux entering out through a body depends on the net charge contained in the body. If the net flux is given to be zero, then it can be inferred that the net charge inside the body is zero.

For the net charge associated with a body to be zero, the body can have equal amount of positive and negative charges and thus, it is not necessary that there were no charges inside the box.

**Short Answer Questions 3 Marks**

**1. A particle of mass $m$ and charge $q$ is released from rest in a uniform electric field of intensity $E$. Calculate the kinetic energy attained by this particle after moving a distance between the plates.**

**Ans:** We have the electrostatic force on a charge $q$ in electric field $E$ given by,

$F=qE$ ……(1)

Also, we have Newton's second law of motion given by,

$F=ma$ ……(2)

From (1) and (2),

$a=\frac{qE}{m}$…… (3)

We have the third equation of motion given by,

$v^2-u^2=2as$

Since the charged particle is initially at rest,

$u=0$

$\Rightarrow v^2=2as$ ……(4)

We have the expression for kinetic energy given by,

$KE=\frac{1}{2}mv^2$ …… (5)

Substituting (4) in (5) we get,

$KE=\frac{1}{2}m(2as)=mas$ ……(6)

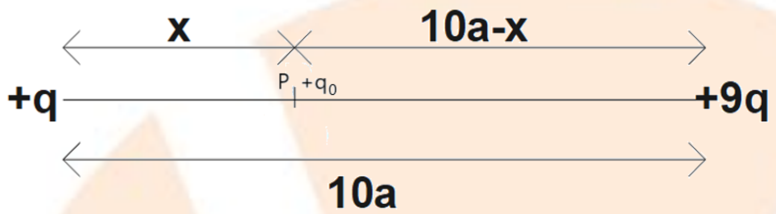
Substituting (3) in (6) to get,

$KE=m\times\left(\frac{qE}{m}\right)\times s$

Therefore, we have the kinetic energy attained by the particle of charge $q$ on moving a distance $s$ in electric field $E$ given by,

$\therefore KE = qEs$

**2. Two charges $+q$ and $+9q$ are separated by a distance of $10a$. Find the point on the line joining the two charges where electric field is zero.**




**Ans:** Let $P$ be the point (at $x$ distance from charge $+q$) on the line joining the given two charges where the electric field is zero.

We know that the electric field at a point at $r$ distance from any charge $q$ is given by,

$$E = K\frac{q}{r^2}$$

Electric field due to charge $+q$ at point $P$ would be,

$$E_1 = K\frac{(+q)}{x^2} \quad \ldots\ldots(1)$$

Electric field due to charge $+9q$ at point $P$ would be,

$$E_2 = K\frac{(+9q)}{(10a - x)^2} \quad \ldots\ldots(2)$$

Since the net electric field at point $P$ is zero,

$$E_1 + E_2 = 0$$

$$\Rightarrow |E_1| = |E_2|$$

From (1) and (2),

$$\Rightarrow \cancel{K}\frac{\cancel{q}}{x^2} = \cancel{K}\frac{9\cancel{q}}{(10a - x)^2}$$

$$\Rightarrow (10a - x)^2 = 9x^2$$

$$\Rightarrow 10 - x = 3x$$

$$\Rightarrow 10a = 4x$$

$$\therefore x = \frac{10}{4}a = 2.5a$$

Therefore, we found the point on the line joining the given two charges where the net electric field is zero to be at a distance $x = 2.5a$ from charge $q$ and at a distance

$10a - x = 10a - 2.5a = 7.5a$ from charge $9q$.

**3.**

**a) Define the term dipole moment $\vec{P}$ of an electric dipole indicating its direction and also give its S.I. unit.**

**Ans:** Electric dipole moment is defined as the product of the magnitude of either of the two charges of the dipole and their distance of separation which would be the length of dipole. Mathematically,

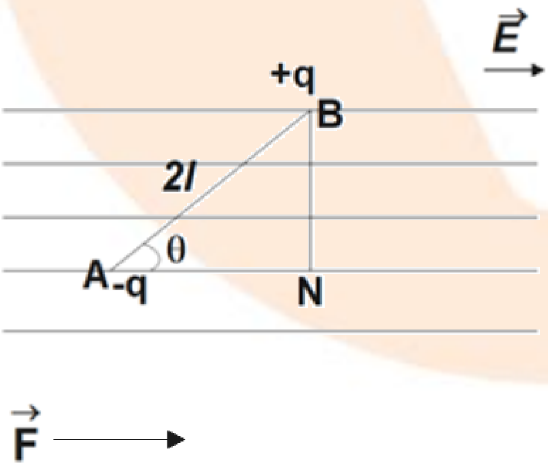
$\vec{P} = 2\vec{l}q$...... (1)

where $2\vec{l}$ is the length of the dipole and $q$ is the charge.

The direction of dipole is from $-ve$ to $+ve$ charge and its S.I. unit is coulomb meter $(Cm)$

**b) An electric dipole is placed in a uniform electric field $\vec{E}$. Deduce the expression for the torque acting on it.**

**Ans.** Consider a dipole placed in uniform electric field $\vec{E}$ making an angle $\theta$ with it.




Now, we know that the force acting on the given dipole will be the electrostatic force and this will be the cause for the resultant force. We have the expression for torque given by,
$\tau = F \times x$ ......(2)

Where, $F$ is the force on the dipole and $x$ is the perpendicular distance.
Where, force $F$ is given by,
$F = qE$ ......(3)
From the figure we have,

$$\sin\theta = \frac{BN}{AB}$$

$$\Rightarrow BN = AB\sin\theta = 2l\sin\theta$$

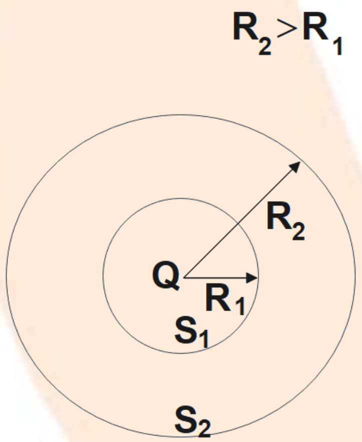
But $BN$ here is the perpendicular distance $x$, so, equation (2) becomes,

$$\tau = qE \times 2l\sin\theta = (2lq)E\sin\theta$$

But from (1), $P = 2lq$
Now, we could give the torque on the dipole as,

$$\therefore \tau = PE\sin\theta = \vec{P} \times \vec{E}$$

**4. A sphere $S_1$ of radius $R_1$ encloses a charge $Q$. If there is another concentric sphere $S_2$ of radius $R_2 (R_2 > R_1)$ and there is no additional change between $S_1$ and $S_2$, then find the ratio of electric flux through $S_1$ and $S_2$.**




**Ans:** We may recall that the expression for electric flux through a surface enclosing charge $q$ by Gauss's law is given by,

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

Where, $\varepsilon_0$ is the permittivity of the medium.
Now the electric flux through sphere $S_1$ is given by,

$$\phi_{S_1} = \frac{Q}{\varepsilon_0} \text{ ...... (1)}$$

Since there is no additional charge between the given two spheres, the flux through sphere $S_2$ is given by,

$\phi_{S_2} = \frac{Q}{\varepsilon_0}$...... (2)

We could now get the ratio of flux through spheres $S_1$ and $S_2$,

$$\frac{\phi_{S_1}}{\phi_{S_2}} = \frac{\frac{Q}{\varepsilon_0}}{\frac{Q}{\varepsilon_0}}$$

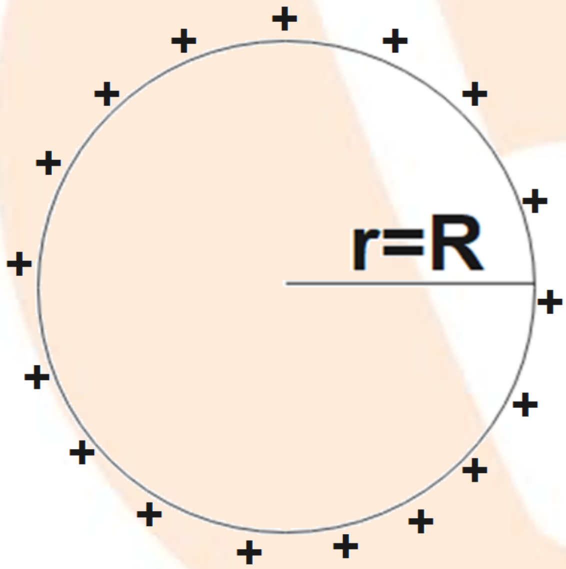
$$\therefore \frac{\phi_{S_1}}{\phi_{S_2}} = \frac{1}{1}$$

Therefore, we find the required ratio to be $1:1$.

**5. Electric charge is uniformly distributed on the surface of a spherical balloon. Show how electric intensity and electric potential vary**

**a) on the surface**

**Ans:**




Electric field intensity on the surface of the balloon would be,

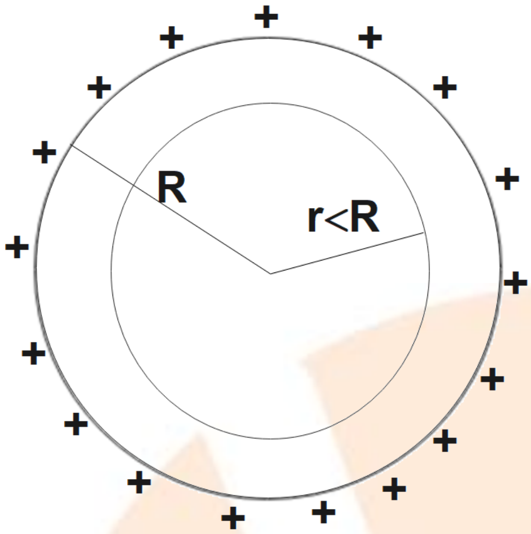
$$E = \frac{\sigma}{\varepsilon_0}$$

Electric potential on the surface of the balloon would be,

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

**b) inside**

**Ans:**




Electric field intensity inside the balloon would be,

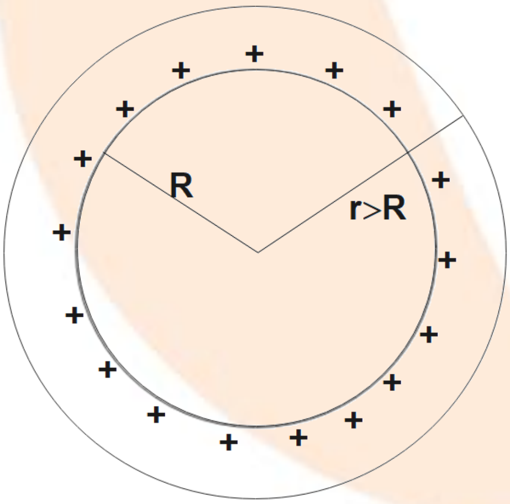
$E = 0$

Electric potential inside the balloon would be,

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

**c) outside.**

**Ans:**



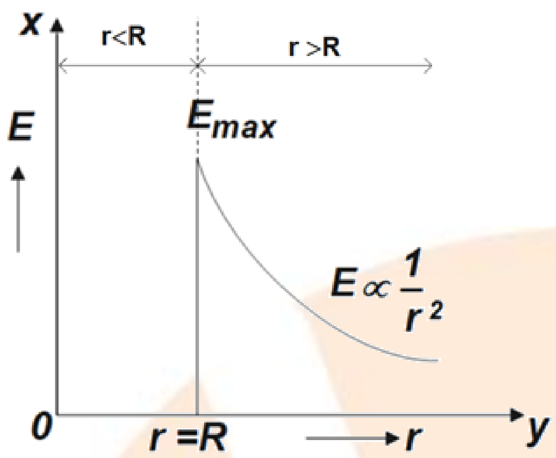

Electric field intensity outside the balloon would be,

$$E = \frac{\sigma}{\varepsilon_0}\frac{R^2}{r^2}$$

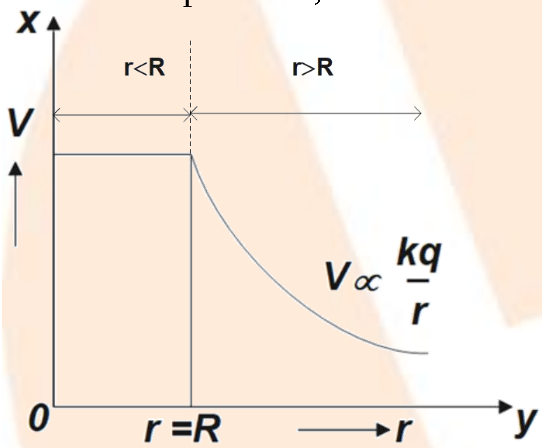
Electric potential outside the balloon would be

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

We could represent this variation graphically as, For electric field,

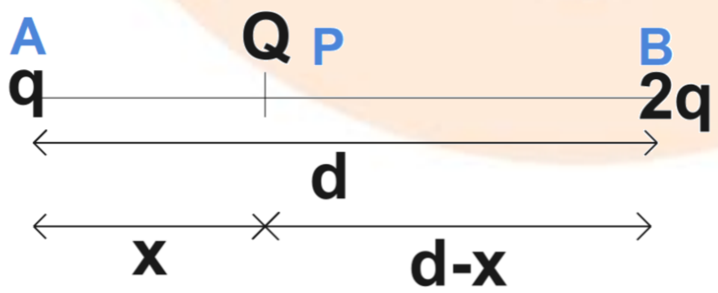



For electric potential,




**6. Two point electric charges $q$ and $2q$ are kept at a distance $d$ apart from each other in air. A third charge $Q$ is to be kept along the same line in such a way that the net force acting on $q$ and $2q$ is zero. Calculate the position of charge $Q$ in terms of $q$ and $d$.**

**Ans:**




For the net force on charge $q$ and $2q$ to be zero, the third charge should be negative since other two given charges are positive.

The force between two charges $q_1$ and $q_2$ separated by a distance $r$ is given by

Coulomb's law as,

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

Force acting on charge $Q$ due to $q = \frac{1}{4\pi\varepsilon_0}\frac{qQ}{x^2}$

Force acting on charge $Q$ due to $2q = \frac{1}{4\pi\varepsilon_0}\frac{2qQ}{(d-x)^2}$

Now for the given system to be in equilibrium,

$$K\frac{Qq}{x^2} = K\frac{2Qq}{(d-x)^2} \ldots\ldots (1)$$

From equations (1) and (2) we get,

$$\frac{1}{x^2} = \frac{2}{(d-x)^2}$$

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

$$\Rightarrow \sqrt{2}x = d - x$$

$$\therefore x = \frac{d}{\sqrt{2}+1}$$

So, we found that the new charge $Q$ should be kept between the given two charges at a distance of $x = \frac{d}{\sqrt{2}+1}$ from charge $q$.

**7. What is the force between two small charged spheres having charges of $2\times10^{-7}C$ and $3\times10^{-7}C$ placed $30cm$ apart in air?**

**Ans:** We are given:

Charge of the first sphere, $q_1 = 2\times10^{-7}C$

Charge of the second sphere, $q_2 = 3\times10^{-7}C$

Distance between the two spheres, $r = 30cm = 0.3m$

Electrostatic force between the spheres is given by Coulomb's law as,

$$F = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2} \ldots\ldots (1)$$

Where, $\varepsilon_0$ = Permittivity of free space and, $\frac{1}{4\pi\varepsilon_0} = 9\times10^9 Nm^2C^2$

Substituting the given values in (1), we get,

$$F = \frac{9\times10^9\times2\times10^{-7}\times3\times10^{-7}}{(0.3)^2}$$

$$\therefore F = 6\times10^{-3}N$$

Hence, force between the two small charged spheres is found to have a magnitude of $6\times10^{-3}N$.
Since both the given charges are positive, the resultant force would be repulsive as like charges repel each other.

**8. The electrostatic force on a small sphere of charge $0.4\mu C$ due to another small sphere of charge $-0.8\mu C$ in air is $0.2N$.**

**a) What is the distance between the two spheres?**

**Ans:** It is given that:

Electrostatic force on the first sphere, $F=0.2N$
Charge on the first sphere, $q_1=0.4\mu C=0.4\times10^{-6}C$
Charge on the second sphere, $q_2=-0.8\mu C=-0.8\times10^{-6}C$
Electrostatic force between the spheres could be given by Coulomb's law as,

$F=\frac{q_1q_2}{4\pi\varepsilon_0 r^2}$ …… (1)

Where, $\varepsilon_0$ = Permittivity of free space and, $\frac{1}{4\pi\varepsilon_0}=9\times10^9 Nm^2C^2$

Rearranging (1) we get,

$$\Rightarrow r^2=\frac{q_1q_2}{4\pi\varepsilon_0 F}$$

Substituting the given values,

$$\Rightarrow r^2=\frac{0.4\times10^{-6}\times-0.8\times10^{-6}\times9\times10^9}{0.2}$$

$$\Rightarrow r^2=144\times10^{-4}$$

$$\Rightarrow r=\sqrt{144\times10^{-4}}$$

$$\therefore r=0.12m$$

Therefore, we found the distance between the given two spheres to be $0.2m$.

**b) What is the force on the second sphere due to the first?**

**Ans:** Since, both the spheres attract each other with the same force, the force on the second sphere due to the first would be $0.2N$.

**9. A polythene piece rubbed with wool is found to have a negative charge of $3\times10^{-7}C$.**

**a) Estimate the number of electrons transferred (from which to which?)**

**Ans:** When polythene is rubbed against wool, certain number of electrons get

transferred from wool to polythene.
Hence, wool becomes positively charged on loosing electrons and polythene becomes negatively charged on gaining them.
Charge on the polythene piece,
$q = -3 \times 10^{-7} C$
Charge of an electron,
$e = -1.6 \times 10^{-19} C$
Let the number of electrons transferred from wool to polythene be $n$, then, from the property of quantization of charge we have,
$q = ne$
$\Rightarrow n = \frac{q}{e}$
Now, on substituting the given values, we get,
$\Rightarrow n = \frac{-3 \times 10^{-7}}{-1.6 \times 10^{-19}}$
$\therefore n = 1.87 \times 10^{12}$
Therefore, the number of electrons transferred from wool to polythene is found to be $1.87 \times 10^{12}$.

b) **Is there a transfer of mass from wool to polythene?**

**Ans:** Yes, during the transfer of electrons from wool to polythene, along with charge, mass is also transferred.
Let $m$ be the mass being transferred in the given case and $m_e$ be the mass of the electron, then,
$m = m_e \times n$
$\Rightarrow m = 9.1 \times 10^{-31} \times 1.85 \times 10^{12}$
$\therefore m = 1.706 \times 10^{-18} kg$
Hence, we found that a negligible amount of mass does get transferred from wool to polythene.

**10. Consider a uniform electric field $E = 3 \times 10^{3} \hat{i} N/C$.**

a) **What is the flux of this field through a square of side $10cm$ whose plane is parallel to the y-z plane?**

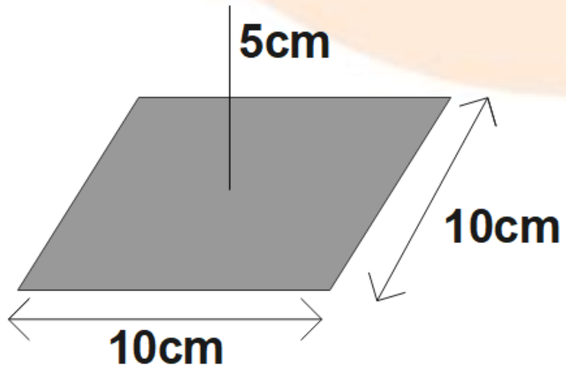
**Ans:** It is given that:
Electric field intensity, $\vec{E} = 3 \times 10^{3} \hat{i} N/C$
Magnitude of electric field intensity, $|\vec{E}| = 3 \times 10^{3} N/C$
Side of the square, $a = 10cm = 0.1m$

Area of the square, $A = a^2 = 0.01 m^2$
Since the plane of the square is parallel to the y-z plane, the normal to its plane would be directed in the x direction. So, angle between normal to the plane and the electric field would be, $\theta = 0°$
We know that the flux through a surface is given by the relation,
$\phi = EA\cos\theta$
Substituting the given values, we get,
$\Rightarrow \phi = 3\times10^3 \times 0.01 \times \cos 0°$
$\therefore \phi = 30 Nm^2/C$
Now, we found the net flux through the given surface to be, $\phi = 30 Nm^2/C$.

**b) What is the flux through the same square if the normal to its plane makes $60°$ angle with the x-axis?**

**Ans:** When the plane makes an angle of $60°$ with the x-axis, the flux through the given surface would be,
$\phi = EA\cos\theta$
$\Rightarrow \phi = 3\times10^3 \times 0.01 \times \cos 60°$
$\Rightarrow \phi = 30 \times \frac{1}{2}$
$\therefore \phi = 15 Nm^2/C$
So, we found the flux in this case to be, $\phi = 15 Nm^2/C$.

**11. A point charge $+10\mu C$ is a distance $5cm$ directly above the center of a square of side $10cm$, as shown in Fig. 1.34. What is the magnitude of the electric flux through the square? (Hint: Think of the square as one face of a cube with edge $10cm$)**
**Ans:** Considering square as one face of a cube of edge $10cm$ with a charge $q$ at its center, according to Gauss's theorem for a cube, total electric flux is through all its six faces.



$\phi_{total} = \frac{q}{\varepsilon_0}$

The electric flux through one face of the cube could be given by, $\phi = \frac{\phi_{total}}{6}$

$\Rightarrow \phi = \frac{1}{6}\frac{q}{\varepsilon_0}$

Permittivity of free space, $\varepsilon_0 = 8.854 \times 10^{-12} N^{-1}C^2m^{-2}$.

The net charge enclosed, $q = 10\mu C = 10 \times 10^{-6} C$.

Substituting the values given in the question, we get,

$\phi = \frac{1}{6} \times \frac{10 \times 10^{-6}}{8.854 \times 10^{-12}}$

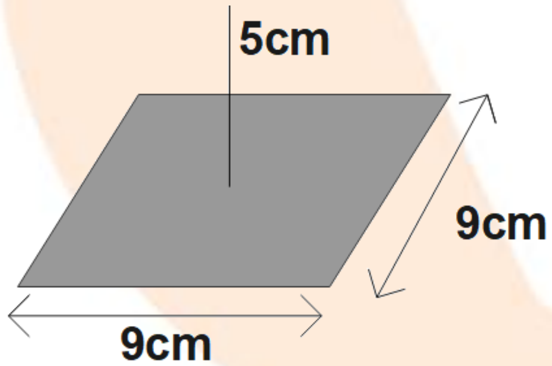
$\therefore \phi = 1.88 \times 10^5 Nm^2C^{-1}$

Therefore, electric flux through the square is found to be $1.88 \times 10^5 Nm^2C^{-1}$.

**12. A point charge of $2.0\mu C$ is kept at the center of a cubic Gaussian surface of edge length $9cm$. What is the net electric flux through the surface?**

**Ans:** Let us consider one of the faces of the cubical Gaussian surface considered, which would be a square.

Since, a cube has six such square faces in total, we could say that the flux through one surface would be one-sixth the total flux through the gaussian surface considered.




The net flux through the cubical Gaussian surface by Gauss's law is given by,

$\phi_{total} = \frac{q}{\varepsilon_0}$

So, the electric flux through one face of the cube would be,

$\phi = \frac{\phi_{total}}{6}$

$\Rightarrow \phi = \frac{1}{6}\frac{q}{\varepsilon_0}$ ...... (1)

But we have, permittivity of free space, $\varepsilon_0 = 8.854 \times 10^{-12} N^{-1}C^2m^{-2}$.

Charge enclosed, $q = 10\mu C = 10 \times 10^{-6} C$.
Substituting the given values in (1) we get,

$$\phi = \frac{1}{6} \times \frac{10 \times 10^{-6}}{8.854 \times 10^{-12}}$$

$$\therefore \phi = 1.88 \times 10^{5} Nm^{2}C^{-1}$$

Therefore, electric flux through the square surface is $1.88 \times 10^{5} Nm^{2}C^{-1}$.

**13. A point charge causes an electric flux of $-1.0 \times 10^{3} Nm^{2} / C$ to pass through a spherical Gaussian surface of $10cm$ radius centered on the charge.**

**a) If the radius of the Gaussian surface were doubled, how much flux would pass through the surface?**

**Ans:** Electric flux due to the given point charge,

$$\phi = -1.0 \times 10^{3} Nm^{2} / C$$

Radius of the Gaussian surface enclosing the point charge,

$$r = 10.0cm$$

Electric flux piercing out through a surface depends on the net charge enclosed by the surface from Gauss's law.
It is independent of the dimensions of the arbitrary surface assumed to enclose this charge.
If the radius of the Gaussian surface is doubled, then the flux passing through the surface remains the same i.e., $-10^{3} Nm^{2} / C$.

**b) What is the value of the point charge?**

**Ans:** Electric flux is given by the relation,

$$\phi_{total} = \frac{q}{\varepsilon_0}$$

Where,
$q =$ net charge enclosed by the spherical surface
Permittivity of free space, $\varepsilon_0 = 8.854 \times 10^{-12} N^{-1}C^{2}m^{-2}$

$$\Rightarrow q = \phi\varepsilon_0$$

Substituting the given values,

$$\Rightarrow q = -1.0 \times 10^{3} \times 8.854 \times 10^{-12} = -8.854 \times 10^{-9} C$$

$$\therefore q = -8.854nC$$

Therefore, the value of the point charge is found to be $-8.854nC$.

**14. A conducting sphere of radius $10cm$ has an unknown charge. If the electric field at a point $20cm$ from the center of the sphere of magnitude**

**$1.5\times10^{3}N/C$ is directed radially inward, what is the net charge on the sphere?**

**Ans:** We have the relation for electric field intensity $E$ at a distance $d$ from the center of a sphere containing net charge $q$ is given by,

$$E=\frac{q}{4\pi\varepsilon_0 d^2} \quad \ldots\ldots (1)$$

Where,

Net charge,

$q=1.5\times10^{3}N/C$

Distance from the center,

$d=20cm=0.2m$

Permittivity of free space,

$\varepsilon_0=8.854\times10^{-12}N^{-1}C^{2}m^{-2}$

$$\frac{1}{4\pi\varepsilon_0}=9\times10^{9}Nm^{2}C^{-2}$$

From (1), the unknown charge would be,

$q=E(4\pi\varepsilon_0)d^2$

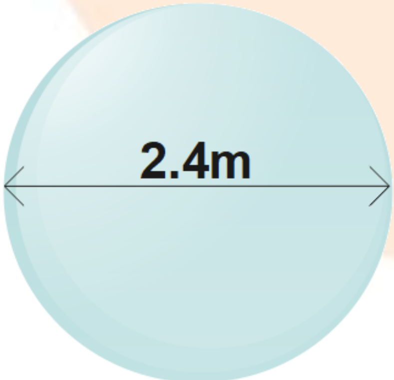
Substituting the given values we get,

$$q=\frac{1.5\times10^{3}\times(0.2)^{2}}{9\times10^{9}}=6.67\times10^{-9}C$$

$\therefore q=6.67nC$

Therefore, the net charge on the sphere is found to be $6.67nC$.

**15. A uniformly charged conducting sphere of $2.4m$ diameter has a surface charge density of $80.0\mu C/m^2$.**




**a) Find the charge on the sphere.**

**Ans:** Diameter of the sphere,

$d=2.4m$

Radius of the sphere,

$r = 1.2m$

Surface charge density,

$\sigma = 80.0\mu C/m^2 = 80\times10^{-6} C/m^2$

Total charge on the surface of the sphere,

$Q = \text{Charge density} \times \text{Surface area}$

$\Rightarrow Q = \sigma\times4\pi r^2 = 80\times10^{-6}\times4\times3.14\times(1.2)^2$

$\therefore Q = 1.447\times10^{-3} C$

Therefore, the charge on the sphere is found to be $1.447\times10^{-3} C$.

**b) What is the total electric flux leaving the surface of the sphere?**

**Ans:** Total electric flux $(\phi_{total})$ leaving out the surface containing net charge $Q$ is given by Gauss's law as,

$\phi_{total} = \frac{Q}{\varepsilon_0}$ …… (1)

Where, permittivity of free space,

$\varepsilon_0 = 8.854\times10^{-12} N^{-1}C^2m^{-2}$

We found the charge on the sphere to be,

$Q = 1.447\times10^{-3} C$

Substituting these in (1), we get,

$\phi_{total} = \frac{1.447\times10^{-3}}{8.854\times10^{-12}}$

$\therefore \phi_{total} = 1.63\times10^{-8} NC^{-1}m^2$

Therefore, the total electric flux leaving the surface of the sphere is found to be $1.63\times10^{-8} NC^{-1}m^2$.

**16. An infinite line charge produces a field of magnitude $9\times10^4 N/C$ at a distance of $2cm$. Calculate the linear charge density.**

**Ans:** Electric field produced by the given infinite line charge at a distance $d$ having linear charge density $\lambda$ could be given by the relation,

$E = \frac{\lambda}{2\pi\varepsilon_0 d}$

$\Rightarrow \lambda = 2\pi\varepsilon_0 Ed$ …… (1)

We are given:

$d = 2cm = 0.02m$

$E = 9\times10^4 N/C$

Permittivity of free space,

$\varepsilon_0 = 8.854\times10^{-12} N^{-1}C^2m^{-2}$

Substituting these values in (1) we get,

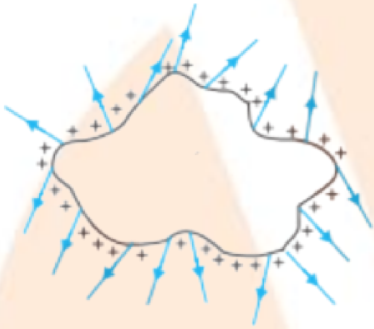
$\lambda = 2\pi\left(8.854\times10^{-12}\right)\left(9\times10^{4}\right)(0.02)$

$\therefore \lambda = 10\times10^{-8}\,C/m$

Therefore, we found the linear charge density to be $10\times10^{-8}\,C/m$ .

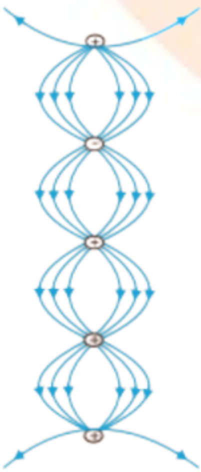
**17. Which among the curves shown in Fig. 1.35 cannot possibly represent electrostatic field lines?**

**a)**



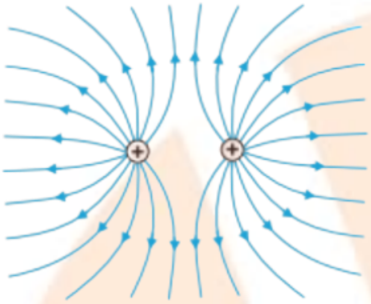
**Ans:** The field lines showed in (a) do not represent electrostatic field lines because field lines must be normal to the surface of the conductor which is a characterizing property of electric field lines.

**b)**



**Ans:** The lines showed in (b) do not represent electrostatic field lines because field lines cannot emerge from a negative charge and cannot terminate at a positive charge since the direction of the electric field is from positive to negative charge.

**c)**

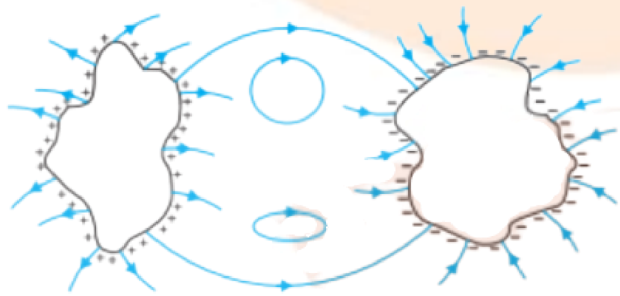


**Ans:** The field lines showed in (c) do represent electrostatic field lines as they are directed outwards from positive charge in accordance with the property of electric field.

**d)**

**Ans:** The field lines showed in (d) do not represent electrostatic field lines because electric field lines should not intersect each other.

**e)**



**Ans:** The field lines showed in (e) do not represent electrostatic field lines because electric field lines do not form closed loops

**18. Suppose that the particle in Exercise in 1.33 is an electron projected with velocity $v_x = 2.0\times10^6 ms^{-1}$. If $E$ between the plates separated by $0.5cm$ is $9.1\times10^2 N/C$, where will the electron strike the upper plate? ( $|e| = 1.6\times10^{-19} C, m_e = 9.1\times10^{-31} kg$ )**

**Ans:** We are given the velocity of the particle, $v_x = 2.0\times10^6 ms^{-1}$

Separation between the two plates, $d = 0.5cm = 0.005m$

Electric field between the two plates, $E = 9.1\times10^2 N/C$

Charge on an electron, $e = 1.6\times10^{-19} C$

mass of an electron, $m_e = 9.1\times10^{-31} kg$

Let $s$ be the deflection when the electron strikes the upper plate at the end of the plate $L$, then, we have the deflection given by,

$$s = \frac{qEL^2}{2mv_x}$$

$$\Rightarrow L = \sqrt{\frac{2dmv_x}{qE}}$$

Substituting the given values,

$$L = \sqrt{\frac{2\times0.005\times9.1\times10^{-31}\times\left(2.0\times10^6\right)^2}{1.6\times10^{-19}\times9.1\times10^2}} = \sqrt{0.025\times10^{-2}} = \sqrt{2.5\times10^{-4}}$$

$$\therefore L = 1.6\times10^{-2} = 1.6cm$$

Therefore, we found that the electron will strike the upper plate after travelling a distance of $1.6cm$.

**Short Answer Questions 5 Marks**

**1.**

**a) The expression of electric field $\vec{E}$ due to a point charge at any point near to it is defined by $\vec{E} = \lim_{q\to0}\frac{\vec{F}}{q}$ where $q$ is the test charge and $\vec{F}$ is the force acting on it. What is the significance of $\lim_{q\to0}$ in this expression?**

**Ans.** The significance of $\lim_{q\to0}$ is that the test charge should be vanishingly small so that it is not disrupting the presence of the source charge.

b) **Two charges each of magnitude $2\times10^{-7}C$ but opposite in sign forms a system. These charges are located at points $A\left(0,0,-10\right)$ and $B\left(0,0,+10\right)$ respectively. Distances are given in cm. What is the total charge and electric dipole moment of the system?**

**Ans.** Total charge of the system $=(+2\times10^{-7})+(-2\times10^{-7})=0$.

Electric dipole moment is:

$P=q\times2l$

$P=2\times10^{-7}\times20\times10^{-2}$

$P=4\times10^{-8}cm$

Also, the direction of electric dipole moment is along the negative z-axis.

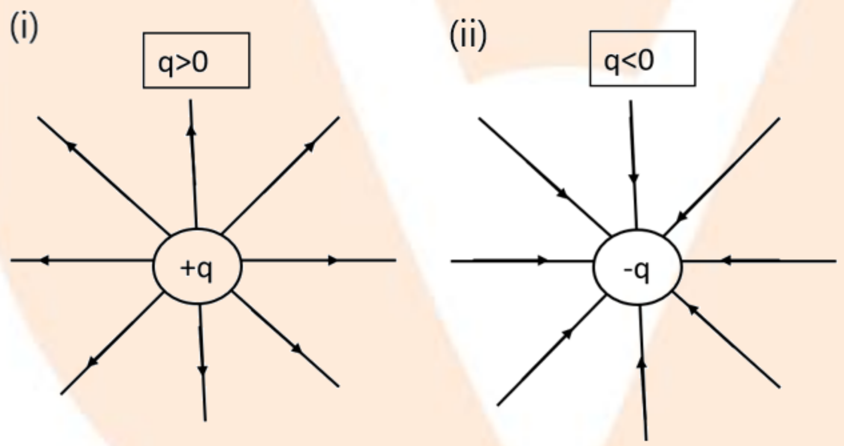
**2.**

a) **Sketch electric lines of force due to**

i. **isolated positive charge (i.e., $q>0$) and**

ii. **isolated negative charge (i.e., $q<0$).**

**Ans.** The sketch of isolated positive charge and isolated negative charge are as follows:



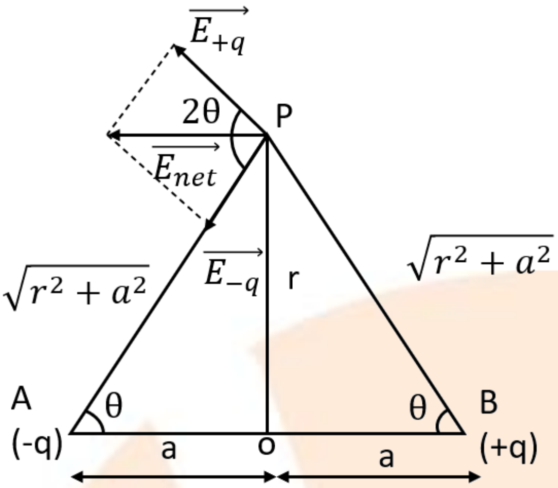

b) **Two-point charges $q$ and $-q$ are placed at a distance of $2a$ apart. Calculate the electric field at a point $P$ situated at a distance $r$ along the perpendicular bisector of the line joining the charges. What is the electric field when $r \gg a$?**

**Ans.** As we know,

$$|\vec{E}_{+q}|=\frac{kq}{r^2+a^2}$$

$$|\vec{E}_{-q}|=\frac{kq}{r^2+a^2}$$

Since, $|\vec{E}_{+q}|=|\vec{E}_{-q}|$




$$|\vec{E}_{net}| = \sqrt{E_{+q}{}^2 + E_{-q}{}^2 + 2E_{+q}E_{-q}\cos 2\theta}$$

$$|\vec{E}_{net}| = \sqrt{2E_{+q}{}^2 + 2E_{+q}{}^2 \cos 2\theta}$$

$$|\vec{E}_{net}| = \sqrt{2E_{+q}{}^2 (1+\cos 2\theta)}$$

$$|\vec{E}_{net}| = \sqrt{2E_{+q}{}^2 (2\cos^2\theta)}$$

$$|\vec{E}_{net}| = \sqrt{4E_{+q}{}^2 (\cos^2\theta)}$$

$$|\vec{E}_{net}| = 2E_{+q}\cos\theta$$

$$|\vec{E}_{net}| = 2E_{+q}\frac{a}{\sqrt{r^2+a^2}}$$

$$|\vec{E}_{net}| = 2\frac{kq}{\sqrt{r^2+a^2}}\frac{a}{\sqrt{r^2+a^2}}$$

$$|\vec{E}_{net}| = \frac{2akq}{(r^2+a^2)^{\frac{3}{2}}}$$

$$|\vec{E}_{net}| = \frac{k\vec{P}}{(r^2+a^2)^{\frac{3}{2}}}$$

For, $r \gg a$ ( $a$ can be neglected)
Therefore, we get,

$$|\vec{E}_{net}| = \frac{k\vec{P}}{r^3}$$

**3.**

**a) What is an equi-potential surface? Show that the electric field is always directed perpendicular to an equi-potential surface.**

**Ans.** An equipotential surface is a surface that has the same potential throughout.
As we know,

$dW = F \cdot dx$

$dW = (q \cdot E) \cdot dx$

(Force on the test charge, $F = (q \cdot E)$)

Since work done is moving a test charge along an equipotential surface is always zero,

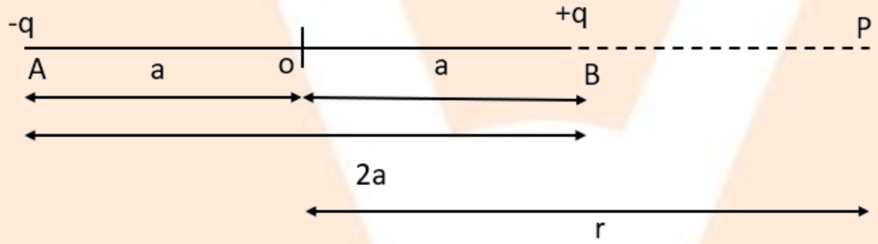
$0 = (q \cdot E) \cdot dx$

$E \cdot dx = 0$

$\Rightarrow E \perp dx$

**b) Derive an expression for the potential at a point along the axial line of a short electric dipole**

**Ans:** Consider an electric dipole of dipole length $2a$ and point $P$ on the axial line such that $OP = r$, where $O$ is the centre of the dipole.




Electric potential at point $P$ due to the dipole is given by:

$$V = V_{PA} + V_{PB}$$

$$V = \frac{K(-q)}{(r+a)} + \frac{K(+q)}{(r-a)}$$

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

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

$$V = Kq\frac{2a}{r^2 - a^2} \qquad (\because P = 2aq)$$

$$V = \frac{KP}{r^2 - a^2}$$

For a dipole having short length, $a$ can be neglected.
This gives,

$V=\frac{KP}{r^2}$

**4. Check if the ratio $\frac{Ke^2}{Gm_em_p}$ is dimensionless. Look up at the table of physical constants and determine the value of this ratio. What does this ratio signify?**

**Ans.** The given ratio is $\frac{Ke^2}{Gm_em_p}$.

Where, $G$ is Gravitational constant. Its unit is $Nm^2kg^{-2}$.

$m_e$ and $m_p$ are the masses of electron and proton respectively. Their unit is $kg$.

$e$ is the electric charge. Its unit is $C$.

$\varepsilon_o$ is the permittivity of free space. Its unit is $Nm^2C^{-2}$.

Therefore, the unit of the given ratio $\frac{Ke^2}{Gm_em_p}$ is

$=\frac{[Nm^2C^{-2}][C^2]}{[Nm^2kg^{-2}][kg][kg]}$

And its dimensions can be related to $=[M^0L^0T^0]$

Hence, the given ratio is dimensionless.

We know,

$e=1.6\times10^{-19}C$

$G=6.67\times10^{-11}Nm^2kg^{-2}$

$m_e=9.1\times10^{-31}kg$

$m_p=1.66\times10^{-27}kg$

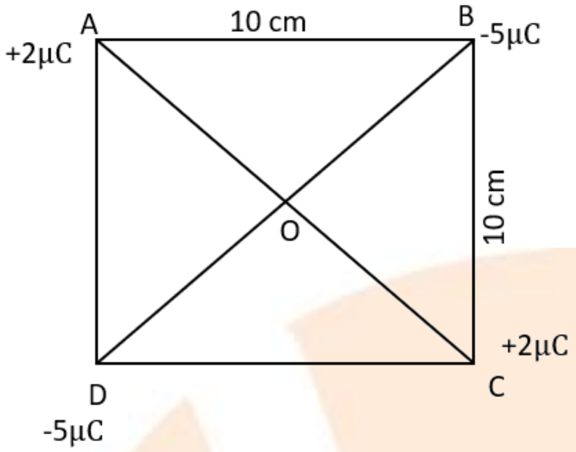
Hence, the numerical value of the given ratio is

$$\frac{Ke^2}{Gm_em_p}=\frac{9\times10^9\times(1.6\times10^{-19})^2}{6.67\times10^{-11}\times9.1\times10^{-31}\times1.66\times10^{-27}}\approx2.3\times10^{39}$$

This ratio is showing the ratio of electric force to the gravitational force between a proton and an electron, keeping distance between them constant.

**5. Four-point charges $q_A=2\mu C$, $q_B=-5\mu C$, $q_C=2\mu C$, $q_D=-5\mu C$ are located at the corners of a square ABCD of side $10$ cm. What is the force on a charge of $1\mu C$ placed at the centre of the square?**

**Ans.** In the given figure, there is a square having length of each side is $10cm$ and four charges placed at its corners. O is the centre of the square.

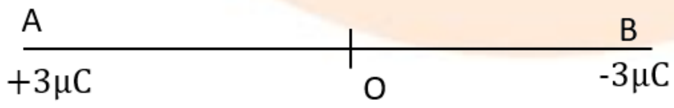



AB, BC, CD and AD are the sides of the square. Each of length is $10\text{cm}$
AC and BD are the diagonals of the square of length $10\sqrt{2}\text{cm}$.
AO, OB, OC, OD are of length $5\sqrt{2}\text{cm}$.
A charge of amount $1\mu\text{C}$ is placed at the centre of square.
There is repulsion force between charges located at A and O is equal in magnitude but having opposite direction relative to the repulsion force between the charges located at C and O. Hence, they will cancel each other forces.
Similarly, there is attraction force between charges located at B and O equal in magnitude but having opposite direction relative to the attraction force between the charge placed at D and O. Hence, they also cancel each other forces.
Therefore, the net force due to the four charges placed at the corners of the square on $1\mu\text{C}$ charge which is placed at centre O is zero.

**6.**

**a) Two-point charges $q_A = 3\mu\text{C}$ and $q_B = -3\mu\text{C}$ are located $20\text{cm}$ apart in vacuum. What is the electric field at the midpoint O of the line AB joining the two charges?**

**Ans.** O is the mid-point of line AB. Distance between the two charges i.e., $AB = 20\text{cm}$




Therefore, $OA = OB = 10\text{cm}$.
Electric field at point O due to $+3\mu\text{C}$ charge:

$$E_1 = \frac{3\times10^{-6}}{4\pi\varepsilon_o (AO)^2}$$

$$E_1 = \frac{3\times10^{-6}}{4\pi\varepsilon_o(10\times10^{-2})^2} NC^{-1}$$ along OB.

Where, $\varepsilon_o$ is the permittivity of free space.

$$\frac{1}{4\pi\varepsilon_o} = 9\times10^9 Nm^2C^{-2}$$ .

Electric field at point O due to $-3\mu C$ charge:

$$E_2 = \frac{3\times10^{-6}}{4\pi\varepsilon_o(OB)^2}$$

$$E_2 = \frac{3\times10^{-6}}{4\pi\varepsilon_o(10\times10^{-2})^2} NC^{-1}$$ along OB.

$$\therefore E = E_1 + E_2$$

$$E = 2\times\frac{9\times10^9\times3\times10^{-6}}{(10\times10^{-2})^2} NC^{-1}$$

[since, $E_1$ and $E_2$ having same values, so, the value is multiplied with 2]

$E = 5.4\times10^6 NC^{-1}$ along OB.

Therefore, the electric field at mid-point O is $5.4\times10^6 NC^{-1}$ along OB.

**b) If a negative test charge of magnitude $1.5\times10^{-9}C$ is placed at this point, what is the force experienced by the test charge?**

**Ans.** A test charge $1.5\times10^{-9}C$ is placed at mid-point O.

$q = 1.5\times10^{-9}C$

Force experienced by test charge, $F = qE$

$F = 1.5\times10^{-9}\times5.4\times10^6$

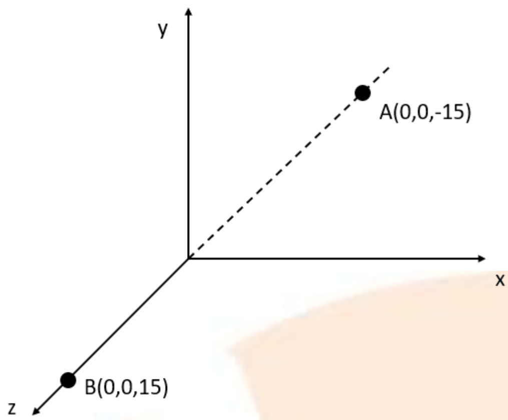
$F = 8.1\times10^{-3}N$

The force is aimed along line OA. The negative test charge is repelled by the charge located at point B but attracted towards A.

Therefore, the force felt by the test charge is $8.1\times10^{-3}N$ along OA.

**7. A system has two charges $q_A = 2.5\times10^{-7}C$ and $q_B = -2.5\times10^{-7}C$ located at points $A(0,0,-15)$ and $B(0,0,15)$ respectively. What are the total charge and electric dipole moment of the system?**

**Ans.** Two charges are located at their respective position.




The value of charge at A, $q_A = 2.5\times10^{-7}C$

The value of charge at B, $q_B = -2.5\times10^{-7}C$

Net amount of charge, $q_{net} = q_A + q_B$

$q_{net} = +2.5\times10^{-7} - 2.5\times10^{-7}$

$q_{net} = 0$

The distance between two charges at A and B,

$d = 15 + 15 = 30cm$

$d = 0.3m$

The electric dipole moment of the system is given by

$P = q_A \times d = q_B \times d$

$P = 2.5\times10^{-7}\times0.3$

$P = 7.5\times10^{-8}Cm$ along z-axis.

Therefore, $7.5\times10^{-8}Cm$ is the electric dipole moment of the system and it is along positive z-axis.

**8.**

**a) Two insulated charged copper spheres A and B have their centres separated by a distance of $50cm$. What is the mutual force of electrostatic repulsion if the charge on each is $6.5\times10^{-7}C$? The radii of A and B are negligible compared to the distance of separation.**

**Ans.** It is given that:

Charges on both A and B is equal to $q_A = q_B = 6.5\times10^{-7}C$

Distance between the centres of the spheres is given as $r = 50cm = 0.5m$

It is known that the force of repulsion between the two spheres would be

$$F = \frac{q_A q_B}{4\pi\varepsilon_0 r^2}$$

where,

$\varepsilon_o$ is the permittivity of the free space

Substituting the known values in the above expression,

$$F=\frac{9\times10^{9}\times(6.5\times10^{-7})^{2}}{(0.5)^{2}}=1.52\times10^{-2}N$$

The mutual force of electrostatic repulsion between the two spheres is $1.52\times10^{-2}N$.

**b) What is the force of repulsion if each sphere is charged double the above amount, and the distance between them is halved?**

**Ans.** Next, it is told that the charges on both the spheres are doubled and the distance between the centres of the spheres is halved. Thus,

$$q_A'=q_B'=2\times6.5\times10^{-7}=13\times10^{-7}C$$

$$r'=\frac{1}{2}(0.5)=0.25m$$

Now, substituting this in the relation for force,

$$F'=\frac{q_A'q_B'}{4\pi\varepsilon_0 r'^2}=\frac{9\times10^{9}\times(13\times10^{-7})^{2}}{(0.25)^{2}}=0.243N$$

The new mutual force of electrostatic repulsion between the two spheres is $0.243N$.

**9. Suppose the spheres A and B in Exercise 1.12 have identical sizes. A third sphere of the same size but uncharged is brought in contact with the first, then brought in contact with the second, and finally removed from both. What is the new force of repulsion between A and B?**

**Ans.** It is given that:

Distance between the spheres A and B is $r=0.5m$

The charge on each sphere initially is $q_A=q_B=6.5\times10^{-7}C$

Now, when uncharged sphere C is made to touch the sphere A, the amount of charge from A will get transferred to the sphere C, making both A and C to have equal charges in them. Clearly,

$$q_A'=q_C=\frac{1}{2}(6.5\times10^{-7})=3.25\times10^{-7}C$$

Now, when the sphere C is made to touch the sphere B, there is similar transfer of charge making both C and B to have equal charges in them. Clearly,

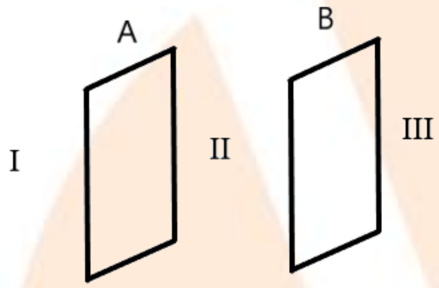
$$q_C'=q_B'=\frac{3.25\times10^{-7}+6.5\times10^{-7}}{2}=4.875\times10^{-7}C$$

Thus, the new force of repulsion between the spheres A and B will turn out to be

$$F' = \frac{q_A' q_B'}{4\pi\varepsilon_0 r^2} = \frac{9\times10^9 \times 3.25\times10^{-7} \times 4.875\times10^{-7}}{(0.5)^2} = 5.703\times10^{-3} N$$

**10. Two large, thin metal plates are parallel and close to each other. On their inner faces, the plates have surface charge densities of opposite signs and of magnitude $17.0\times10^{-22} Cm^{-2}$. What is $E$ in the outer region of the first plate? What is $E$ in the outer region of the second plate? What is E between the plates?**

**Ans:** The given nature of metal plates is represented in the figure below:




Here, A and B are two parallel plates kept close to each other. The outer region of plate A is denoted as I, outer region of plate B is denoted as III, and the region between the plates, A and B, is denoted as II.

It is given that:

Charge density of plate A, $\sigma = 17.0\times10^{-22} C/m^2$

Charge density of plate B, $\sigma = -17.0\times10^{-22} C/m^2$

In the regions I and III, electric field E is zero. This is because the charge is not enclosed within the respective plates.

Now, the electric field E in the region II is given by

$$E = \frac{|\sigma|}{\varepsilon_0}$$

where,

$\varepsilon_0$ = Permittivity of free space $= 8.854\times10^{-12} N^{-1}C^2m^{-2}$

Clearly,

$$E = \frac{17.0\times10^{-22}}{8.854\times10^{-12}}$$

$$\Rightarrow E = 1.92\times10^{-10} N/C$$

Thus, it can be concluded that the electric field between the plates is $1.92\times10^{-10} N/C$.

**11. An oil drop of 12 excess electrons is held stationary under a constant electric field of $2.55\times10^4 NC^{-1}$ in Millikan's oil drop experiment. The density**

**of the oil is $1.26 gm/cm^3$. Estimate the radius of the drop. $\left(g = 9.81 ms^{-2}, e = 1.60 \times 10^{-19} C\right)$.**

**Ans:** It is given that:
The number of excess electrons on the oil drop, n=12
Electric field intensity, $E = 2.55 \times 10^4 NC^{-1}$
The density of oil, $\rho = 1.26 gm/cm^3 = 1.26 \times 10^3 kg/m^3$
Acceleration due to gravity, $g = 9.81 ms^{-2}$
Charge on an electron $e = 1.60 \times 10^{-19} C$
Radius of the oil drop =r
Here, the force (F) due to electric field E is equal to the weight of the oil drop (W).
Clearly,

$$F = W$$
$$Eq = mg$$
$$Ene = \frac{4}{3}\pi r^2 \rho \times g$$

where,
q is the net charge on the oil drop $= ne$
m is the mass of the oil drop $= \text{Volume of the oil drop} \times \text{Density of oil} = \frac{4}{3}\pi r^3 \times p$
Therefore, radius of the oil drop can be calculated as

$$r = \sqrt{\frac{3Ene}{4\pi\rho g}}$$
$$\Rightarrow r = \sqrt{\frac{3 \times 2.55 \times 10^4 \times 12 \times 1.6 \times 10^{-19}}{4 \times 3.14 \times 1.26 \times 10^3 \times 9.81}}$$
$$\Rightarrow r = \sqrt{946.09 \times 10^{-21}}$$
$$\Rightarrow r = 9.72 \times 10^{-10} m$$

Therefore, the radius of the oil drop is $9.72 \times 10^{-10} m$.

**12. In a certain region of space, electric field is along the z-direction throughout. The magnitude of electric field is, however, not constant but increases uniformly along the positive z-direction, at the rate of $10^5 NC^{-1}$ per meter. What are the force and torque experienced by a system having a total dipole moment equal to $10^{-7} Cm$ in the negative z-direction?**

**Ans:** We know that the dipole moment of the system, $P = q \times dl = -10^{-7} Cm$
Also, the rate of increase of electric field per unit length is given as

$$\frac{dE}{dl} = 10^5 NC^{-1}$$

Now, the force (F) experienced by the system is given by $F = qE$

$$F = q\frac{dE}{dl} \times dl$$

$$F = P\frac{dE}{dl}$$

$$\Rightarrow F = -10^{-7} \times 10^{5}$$

$$\Rightarrow F = -10^{-2} N$$

Clearly, the force is equal to $-10^{-2} N$ in the negative z-direction i.e., it is opposite to the direction of electric field.

Thus, the angle between electric field and dipole moment is equal to $180°$.

Now, the torque is given by $\tau = PE\sin\theta$

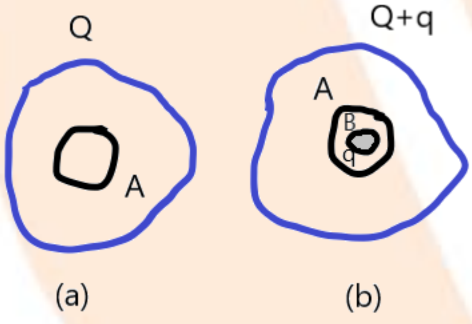
$$\tau = PE\sin 180°$$

$$= 0$$

Therefore, it can be concluded that the torque experienced by the system is zero.

**13.**

**a) A conductor A with a cavity as shown in the Fig. 1.36(a) is given a charge $Q$. Show that the entire charge must appear on the outer surface of the conductor.**




**Ans:** Firstly, let us consider a Gaussian surface that is lying within a conductor as a whole and enclosing the cavity. Clearly, the electric field intensity E inside the charged conductor is zero.

Now, let q be the charge inside the conductor and $\varepsilon_0$, the permittivity of free space.

According to Gauss's law,

Flux is given by

$$\phi = \vec{E}.ds = \frac{q}{\varepsilon_0}$$

Here, $\phi = 0$ as $E = 0$ inside the conductor

Clearly,

$$0=\frac{q}{8.854\times10^{-12}}$$

$\Rightarrow q=0$

Therefore, the charge inside the conductor is zero.
And hence, the entire charge Q appears on the outer surface of the conductor.

**b) Another conductor B with charge q is inserted into cavity keeping B insulated from A. Show that the total charge on the outside surface of A is $Q+q$ [Fig. 1.36 (b)].**

**Ans.** The outer surface of conductor A has a charge of Q.
It is given that another conductor B, having a charge $+q$ is kept inside conductor A and is insulated from the conductor A. Clearly, a charge of $-q$ will get induced in the inner surface of conductor A and a charge of $+q$ will get induced on the outer surface of conductor A. Therefore, the total charge on the outer surface of conductor A amounts to $Q+q$.

**c) A sensitive instrument is to be shielded from the strong electrostatic fields in its environment. Suggest a possible way.**

**Ans.** A sensitive instrument can be shielded from a strong electrostatic field in its environment by enclosing it fully inside a metallic envelope.
Such a closed metallic body provides hindrance to electrostatic fields and thus can be used as a shield.

**14. A hollow charged conductor has a tiny hole cut into its surface. Show that the electric field in the hole is $\left[\frac{\sigma}{2\varepsilon_0}\right]\hat{n}$, where $\hat{n}$ is the unit vector in the outward normal direction, and $\sigma$ is the surface charge density near the hole.**

**Ans:** Firstly, let us consider a conductor with a cavity or a hole. It is known that the electric field inside the cavity is zero.
Let us assume E to be the electric field just outside the conductor, q be the electric charge, $\sigma$ be the charge density, and $\varepsilon_0$, the permittivity of free space.
We know that charge $|q|=\sigma\times d$
Now, according to Gauss's law,

$$\phi=E.ds=\frac{|q|}{\varepsilon_0}$$

$$E.ds=\frac{\sigma\times d}{\varepsilon_0}$$

$$\therefore E = \frac{\sigma}{\varepsilon_0}\hat{n}$$

where $\hat{n}$ is the unit vector in the outward normal direction.

Thus, the electric field just outside the conductor is $\frac{\sigma}{\varepsilon_0}\hat{n}$. Now, this field is actually a superposition of the field due to the cavity $E_1$ and the field due to the rest of the charged conductor $E_2$. These electric fields are equal and opposite inside the conductor whereas equal in magnitude as well as direction outside the conductor. Clearly,

$$E_1 + E_2 = E$$

$$E_1 = E_2 = \frac{E}{2} = \frac{\sigma}{2\varepsilon_0}\hat{n}$$

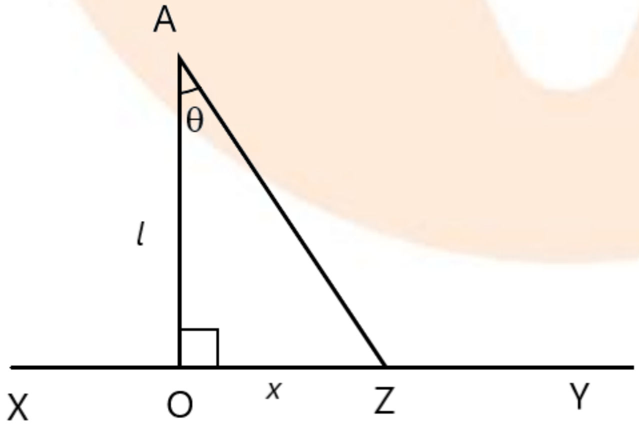
Therefore, the electric field in the hole is $\frac{\sigma}{2\varepsilon_0}\hat{n}$.

Hence, proved.

**15. Obtain the formula for the electric field due to a long thin wire of uniform linear charge density $\lambda$ without using Gauss's law. [Hint: Use Coulomb's law directly and evaluate the necessary integral]**

**Ans:** Firstly, let us take a long thin wire XY as shown in the figure below. This wire is of uniform linear charge density $\lambda$.


Now, consider a point A at a perpendicular distance l from the mid-point O of the wire as shown in the figure below:




Consider E to be the electric field at point A due to the wire.

Also consider a small length element $dx$ on the wire section with $OZ = x$ as

shown.
Let q be the charge on this element.
Clearly, $q=\lambda dx$
Now, the electric field due to this small element can be given as
$$dE=\frac{1}{4\pi\varepsilon_0}\frac{\lambda dx}{(AZ)^2}$$
However, $AZ=\sqrt{1^2+x^2}$
$$\therefore dE=\frac{\lambda dx}{4\pi\varepsilon_0\left(1^2+x^2\right)}$$
Now, let us resolve the electric field into two rectangular components. Doing so, $dE\cos\theta$ is the perpendicular component and $dE\sin\theta$ is the parallel component.
When the whole wire is considered, the component $dE\sin\theta$ gets cancelled and only the perpendicular component $dE\cos\theta$ affects the point A.
Thus, the effective electric field at point A due to the element $dx$ can be written as
$$dE_1=\frac{\lambda dx\cos\theta}{4\pi\varepsilon_0\left(l^2+x^2\right)} \quad ....(1)$$
Now, in $\Delta AZO$, we have
$$\tan\theta=\frac{x}{l}$$
$$x=l\tan\theta \quad ......(2)$$
On differentiating equation (2), we obtain
$$dx=l\sec^2 d\theta \quad ......(3)$$
From equation (2)
$$x^2+l^2=l^2+l^2\tan^2\theta$$
$$\Rightarrow l^2\left(1+\tan^2\theta\right)=l^2\sec^2\theta$$
$$\Rightarrow x^2+l^2=l^2\sec^2\theta \quad .....(4)$$
Putting equations (3) and (4) in equation (1), we obtain
$$dE_1=\frac{\lambda l\sec^2 d\theta}{4\pi\varepsilon_0\left(l^2\sec^2\theta\right)}\cos\theta$$
$$\therefore dE_1=\frac{\lambda\cos\theta d\theta}{4\pi\varepsilon_0 l} \quad .....(5)$$
Now, the wire is taken so long that ends from $-\frac{\pi}{2}$ to $+\frac{\pi}{2}$.
Therefore, by integrating equation (5), we obtain the value of field $E_1$ as

$$\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} dE_1 = \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \frac{\lambda}{4\pi\varepsilon_0 l}\cos\theta d\theta$$

$$\Rightarrow E_1 = \frac{\lambda}{4\pi\varepsilon_0 l}\times 2$$

$$\Rightarrow E_1 = \frac{\lambda}{2\pi\varepsilon_0 l}$$

Thus, the electric field due to the long wire is derived to be equal to $\frac{\lambda}{2\pi\varepsilon_0 l}$.

**16. It is now believed that protons and neutrons (which constitute nuclei of ordinary matter) are themselves built out of more elementary units called quarks. A proton and a neutron consist of three quarks each. Two types of quarks, the so called 'up quark (denoted by $u$) of charge $\left(+\frac{1}{2}\right)e$ and the 'down' quark (denoted by $d$) of charge $-\left(\frac{1}{3}\right)e$ together with electrons build up ordinary matter. (Quarks of other types have also been found which give rise to different unusual varieties of matter.) Suggest a possible quark composition of a proton and neutron.**

**Ans:** It is known that a proton has three quarks. Let us consider n up quarks in a proton, each having a charge of $+\left(\frac{2}{3}e\right)$.

Now, the charge due to n up quarks $=\left(\frac{2}{3}e\right)n$

The number of down quarks in a proton $=3-n$

Also, each down quark has a charge of $-\frac{1}{3}e$

Therefore, the charge due to $(3-n)$ down quarks $=\left(-\frac{1}{3}e\right)(3-n)$

We know that the total charge on a proton $=+e$

Therefore,

$$e=\left(\frac{2}{3}e\right)n+\left(-\frac{1}{3}e\right)(3-n)$$

$$\Rightarrow e=\left(\frac{2ne}{3}\right)-e+\frac{ne}{3}$$

$$\Rightarrow 2e=ne$$

$$\Rightarrow n=2$$

Clearly, the number of up quarks in a proton, $n=2$
Thus, the number of down quarks in a proton $=3-n=3-2=1$
Therefore, a proton can be represented as $uud$.
A neutron is also said to have three quarks. Let us consider $n$ up quarks in a neutron, each having a charge of $+\left(\frac{2}{3}e\right)$.

It is given that the charge on a neutron due to $n$ up quarks $=\left(+\frac{3}{2}e\right)n$

Also, the number of down quarks is $(3-n)$, each having a charge of $=\left(-\frac{3}{2}\right)e$

Thus, the charge on a neutron due to $(3-n)$ down quarks $=\left(-\frac{1}{3}e\right)(3-n)$

Now, we know that the total charge on a neutron $=0$
Thus,

$$0=\left(\frac{2}{3}e\right)n+\left(-\frac{1}{3}e\right)(3-n)$$

$$\Rightarrow 0=\left(\frac{2ne}{3}\right)-e+\frac{ne}{3}$$

$$\Rightarrow e=ne$$

$$\Rightarrow n=1$$

Clearly, the number of up quarks in a neutron, $n=1$
Thus, the number of down quarks in a neutron $=3-n=2$
Therefore, a neutron can be represented as $udd$.

**17.**

**a) Consider an arbitrary electrostatic field configuration. A small test charge is placed at a null point (i.e., where $E=0$) of the configuration. Show that the equilibrium of the test charge is necessarily unstable.**

**Ans:** Firstly, let us assume that the small test charge placed at the null point of the given setup is in stable equilibrium.
By stable equilibrium, it means that even a slight displacement of the test charge in any direction will cause the charge to return to the null point as there will be strong restoring forces acting around it.
This further suggests that all the electric lines of force around the null point act inwards and towards the given null point.
But by Gauss law, we know that the net electric flux through a chargeless enclosing surface is equal to zero. This truth contradicts the assumption which we had started with. Therefore, it can be concluded that the equilibrium of the test charge is necessarily unstable.

b) **Verify this result for the simple configuration of two charges of the same magnitude and sign placed at a certain distance apart.**

**Ans.** When we consider this configuration setup with two charges of the same magnitude and sign placed at a certain distance apart, the null point happens to be at the mid-point of the line joining these two charges.
As per the previous assumption, the test charge, when placed at this mid-point will experience strong restoring forces when it tries to displace itself.
But when the test charge tries to displace in a direction normal to the line joining the two charges, the test charge gets pulled off as there is no restoring force along the normal to the line considered.
Since stable equilibrium prioritizes restoring force in all directions, the assumption in this case also gets contradicted.

**18. A particle of mass $m$ and charge $(-q)$ enters the region between the two charged plates initially moving along x- axis with speed vx (like particle 1 in Fig 1.33). The length of plate is $L$ and a uniform electric field $E$ is maintained between the plates. Show that the vertical deflection of the particle at the far edge of the plate is $\frac{qEL^2}{2mv_x^{\ 2}}$.**

**Compare this motion with motion of a projectile in gravitational field discussed in section 4.10 of class XI textbook of Physics.**

**Ans:** It is given that:
The charge on a particle of mass $m = -q$
Velocity of the particle $= vx$
Length of the plates $= L$
Magnitude of the uniform electric field between the plates $= E$
Mechanical force, $F = \text{Mass (m)} \times \text{Acceleration (a)}$

Thus, acceleration, $a = \frac{F}{m}$

However, electric force, $F = qE$

Therefore, acceleration, $= \frac{qE}{m}$ ......(1)

Here, the time taken by the particle to cross the field of length L is given by,

$t = \frac{\text{Length of the plate}}{\text{Velocity of the plate}} = \frac{L}{v_x}$ ......(2)

In the vertical direction, we know that the initial velocity, $u = 0$
Now, according to the third equation of motion, vertical deflection $s$ of the particle can be derived as

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

$$\Rightarrow s = 0 + \frac{1}{2}\left(\frac{qE}{m}\right)\left(\frac{L}{v_x}\right)^2$$

$$\Rightarrow s = \frac{qEL^2}{2m{v_x}^2} \quad .....(3)$$

Therefore, the vertical deflection of the particle at the far edge of the plate is $\frac{qEL^2}{2m{v_x}^2}$

On comparison, we can see that this is similar to the motion of horizontal projectiles under gravity.