ELECTRIC CHARGES AND FIELD

CHAPTER – 1

ELECTRIC CHARGES AND FIELD

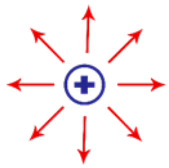
Electrostatics deals with the study of forces, fields and potentials arising from static charges

Electric Charge-

It is the basic physical property of matter and due to this property, a force is experienced when kept in the field of electricity. Electric charges are of two types,

1. **Positive Charge**

   Lesser number of electrons than a number of protons

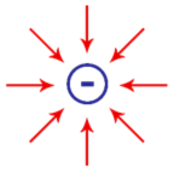


$q > 0$

   Positive charges or protons have a charge of +1.6 × 10^{-19} Coulomb. A positive charge has its field lines emerging from within and going up to infinity

2. **Negative Charge**

   More number of electrons than number of protons



$q < 0$

Negative charges or Electrons have a charge of -1.6 × 10-19 Coulomb. A Negative charge has its field lines coming from infinity.

The above example where hair strands start to attract to the ruler is due to electric charges. Similarly, rubbing a balloon on hair attracts hair to the balloon, in case two balloons are simultaneously rubbed, the balloons will start to repel each other, but they will attract the hair strands.

The rate of change of electric charge is known as Electric current, I = q/t

Did You know

Electric charge, which can be positive or negative, occurs in discrete natural units and is neither created nor destroyed.

Conductors and Insulators

Conductors- Conductors are the materials or substances which allow electricity to flow through them. They conduct electricity because they allow electrons to flow easily inside them from atom to atom. Also, conductors allow the transmission of heat or light from one source to another. Metals, humans, earth, and animals are all conductors. This is the reason we get electric shocks! Moreover, the human body is a good conductor. So it provides a resistance-free path for the current to flow from wire to body. Conductors have free electrons on its surface which allow current to pass through easily. This is the reason why conductors are able to conduct electricity.

Material such as silver is the best conductor of electricity. But it is costly and so, we don't use silver in industries and transmission of electricity. Conductors are quite useful in many ways. They find use in many real-life applications. For example, Mercury is a common material in thermometer to check the temperature of the body. Aluminum finds its use in making foils to store food. It is also used in the production of fry pans to store heat quickly.

Insulators- Insulators are the materials or substances which resist or don't allow the current to flow through them. In general, they are solid in nature. Also, insulators are finding use in a variety of systems. As they do not allow the flow of heat. The property which makes insulators different from conductors is its resistivity. Wood, cloth, glass, mica, and quartz are some good examples of insulators. Also, insulators are protectors. They give protection against heat, sound and of course passage of electricity. Furthermore, insulators don't have any free electrons. It is the main reason why they don't conduct electricity.

Glass is the best insulator as it has the highest resistivity. Plastic is a good insulator and it finds its use in making a number of things. As insulators resist the flow of electron, they find worldwide applications. Thermal insulators, disallow heat to move from one place to another. Hence, we use them in making thermoplastic bottles. They are also used in fireproofing ceilings and walls. Sound insulators help in controlling noise level, as they are good in absorbance of sound. Thus, we use them in buildings and conference halls to make them noise-free.

Charging by induction-

The charging by induction definition states that it is a process of charging conducting bodies without touching them or by bringing the two conducting bodies near to each other. This method of charging is the one in which with the help of a charged object, a neutral object is charged but without touching the objects. The charged particle is brought closer to a neutral or an uncharged conductor which is grounded on a material that is neutrally charged. If a charge flows between two objects, the uncharged conductive material will develop a charge whose polarity will be opposite to that of the charged object.

Basic Properties of Electric Charge

In order to look at the properties of electric charge, consider the electric charges to be really small, known as the Point charge. Point charges are smaller than the distance between them.

Additivity of Electric Charges

Electric charges when they are considered as point charges are scalar in nature. With that, it is important to note that charges can be point charges, but they are still positive and negative charges. The additive property of electric charges says that if there are n number of charges present inside, the total charge present will be the algebraic sum of the individual charges.

$$Q = q_1 + q_2 + q_3 + \dots q_n$$

Conservation of Charges

The Conservation of charges says that the charges are neither created not destroyed. They can be transferred from one body to another, but they cannot be created or destroyed. In an Isolated system, the charges are always conserved.

Quantization of Charge

According to the quantization of electric charge, Electric charges are defined as the Integral multiple of the charge present on them, hence, in any system, The charges will be,

$$q = ne$$

Where, n = Integer numbers e = value of the charge (1.6×10^{-19} C)

Coulomb's law-

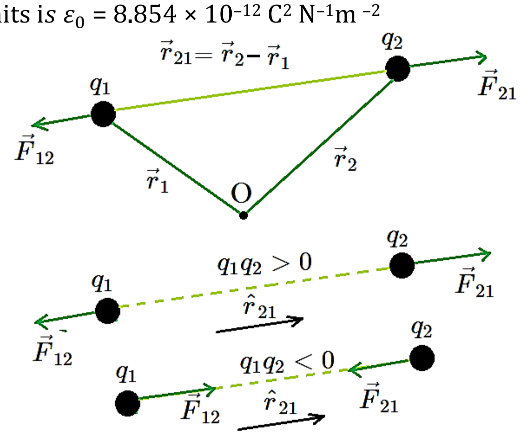
Coulomb's law is a mathematical formula that describes the force between two-point charges. When the size of charged bodies is substantially smaller than the separation between them, then the size is not considered or can be ignored. The charged bodies can be considered as point charges. Coulomb studied the force between two-point charges and found that it is inversely proportional to the square of the distance between them, directly proportional to the product of their magnitudes, and acting in a line that connects them. Expression for Coulomb's Law The amount of the force (F) between two-point charges q1 and q2 separated by a distance r in a vacuum is given by

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

Where F is the force between two-point charges, q_1 and q_2 are the point charge, r is the distance between the point charge and k is proportionality constant. For subsequent simplicity, the constant k in the above expression is commonly written as

$$k = \frac{1}{4\pi\varepsilon_0}$$

Here, ε_0 is called the permittivity of free space. The value of ε0 in SI units is $\varepsilon_0 = 8.854 \times 10^{-12}\ C^2\ N^{-1} m^{-2}$



Coulomb's law is better written in vector notation because force is a vector quantity. Charges q1 and q2 have location vectors r_1 and r_2, respectively. F_{12} denotes force on q_1 owing to q_2 and F_{21} denotes force on q_2 owing to q_1. For convenience, the two-point charges q_1 and q_2 have been numbered 1 and 2, respectively, and the vector leading from 1 to 2 has been designated by r_{21}.

$\overrightarrow{r_{21}} = \overrightarrow{r_2} - \overrightarrow{r_1}$

Similarly, the vector leading from 2 to 1 is denoted by r_{12},

$\overrightarrow{r_{12}} = \overrightarrow{r_1} - \overrightarrow{r_2}$

r_{21} and r_{12} are the magnitudes of the vectors $\overrightarrow{r_{21}}$ and $\overrightarrow{r_{12}}$, respectively and magnitude r_{12} is equal to r_{21}. A unit vector along the vector specifies the vector's direction. The unit vectors are used to denote the direction from 1 to 2 (or 2 to 1) The unit vectors define as,

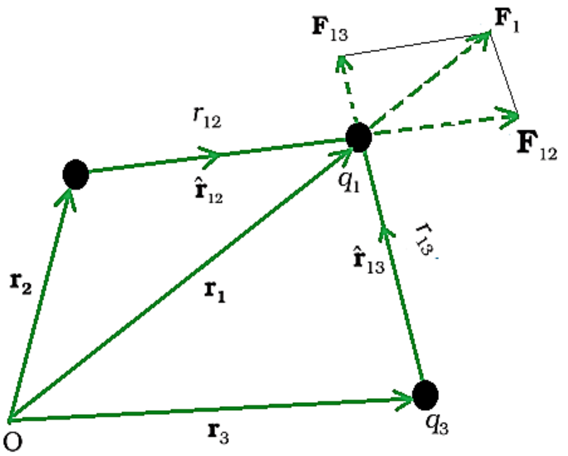
$$\overrightarrow{r_{21}} = \frac{\overrightarrow{r_{12}}}{r_{12}}$$

Coulomb's force law between two-point charges q1 and q2 located at vector r1 and r2 is then expressed as

$$\overrightarrow{F_{21}} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{21}^2}\hat{r}_{21}$$

$$\overrightarrow{F_{21}} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{21}^3}\vec{r}_{21}$$

Forces Between Multiple Charges



Consider a system in a vacuum with n motionless that is stationary charges q_1, q_2, and q_3. It has been proven experimentally that the vector sum of all the forces on a charge due to a number of other charges, taken one at a time, is the vector sum of all the forces on that charge owing to the other charges. Due to the presence of other charges, the separate forces remain unaffected. This is known as the superposition principle. The force on one charge, say q_1, due to two other charges, q_2 and q_3, may be determined by conducting a vector addition of the forces due to each of these charges. As a result, if F_{12} denotes the force exerted on q_1 as a result of q_2

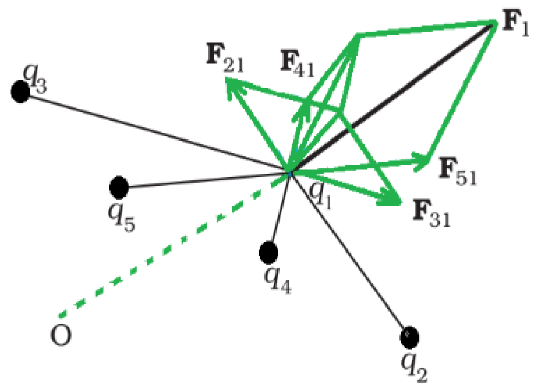
$$\overrightarrow{F_{12}} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}^2}\hat{r}_{12}$$

Similarly, F_{13} denotes the force exerted on q_1 as a result of q_3, which again is the Coulomb force on q_1 due to q_3 even though other charge q_2 is present. Thus, the total force F_1 on q_1 due to the two charges q_2 and q_3 can be expressed as,

$$\overrightarrow{F_1} = \overrightarrow{F_{12}} + \overrightarrow{F_{13}}$$

$$\overrightarrow{F_1} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}^2}\hat{r}_{12} + \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_3}{r_{13}^2}\hat{r}_{13}$$

$$\overrightarrow{F_1} = \frac{q_1}{4\pi\varepsilon_0}\left[\frac{q_2}{r_{12}^2}\hat{r}_{12} + \frac{q_3}{r_{13}^2}\hat{r}_{13}\right]$$



The above force calculation can be applied to a system with more than three charges. The principle of superposition states that in a system of charges q_1, q_2.......q_n, the force on q_1 owing to q_2 is the same as Coulomb's law, i.e., it is unaffected by the presence of other charges q_3, q_4,..., q_n. The vector sum of the forces F_{12}, F_{13}, F_{1n} on the charge q_1 owing to all other charges gives the overall force F_1 can be written as

$$\overrightarrow{F_1} = \overrightarrow{F_{12}} + \overrightarrow{F_{13}} + \cdots + \overrightarrow{F_{1n}}$$

$$\overrightarrow{F_1} = \frac{q_1}{4\pi\varepsilon_0}\left[\frac{q_2}{r_{12}^2}\hat{r}_{12} + \frac{q_3}{r_{13}^2}\hat{r}_{13} + \cdots + \frac{q_n}{r_{1n}^2}\hat{r}_{1n}\right]$$

$$\overrightarrow{F_1} = \frac{q_1}{4\pi\varepsilon_0}\sum_{i=2}^{n}\frac{q_i}{r_{1i}^2}\hat{r}_{1i}$$

The vector sum is calculated by using the parallelogram law of vector addition. Coulomb's law and the superposition principle are the foundations of electrostatics.

Q. **Two equal point charges (10^{-3}C) are placed 1cm apart in medium of dielectric constant K=5.**
(a) find the interaction force between the point charges
(b) Net force on any of the charge

Sol. (a) Interaction force between point charges is,

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

F = $9 \times 10^9 \frac{(10^{-3})^2}{(10^{-2})^2}$ F = $9 \times 10^7 N$

interaction force between point charges is $9 \times 10^7 N$

(b) Net force on any of the charges-

$$F' = \frac{1}{4\pi\epsilon_0 k}\frac{q_1 q_2}{r^2} = \frac{9\times10^9}{5}\frac{(10^{-3})^2}{(10^{-2})^2}$$

F' = $18 \times 10^6 N$

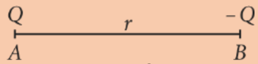
Net force on any of the charges is $18 \times 10^6 N$

Q. Two-point charges A and B, having charges $+Q$ and $-Q$ respectively, are placed at certain distance apart and force acting between them is F. If 25% charge of A is transferred to B, then force between the charges becomes

(a) $\frac{4F}{3}$ (b) F (c) $\frac{9F}{16}$ (d) $\frac{16F}{9}$

Sol. **Ans. (c) $\frac{9F}{16}$**

In case I:



$F = -\frac{1}{4\pi\varepsilon_0}\frac{Q^2}{r^2}$ ...(i)

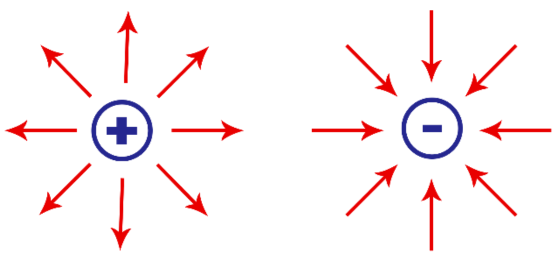
In Case II: $Q_A = Q - \frac{Q}{4}, Q_B = -Q + \frac{Q}{4}$

$\therefore F' = \frac{1}{4\pi\varepsilon_0}\frac{\left(Q-\frac{Q}{4}\right)\left(-Q+\frac{Q}{4}\right)}{r^2}$

$= \frac{1}{4\pi\varepsilon_0}\frac{\left(\frac{3}{4}Q\right)\left(\frac{-3}{4}Q\right)}{r^2} = -\frac{1}{4\pi\varepsilon_0}\frac{9}{16}\frac{Q^2}{r^2}$ ...(ii)

From equations (i) and (ii), $F' = \frac{9}{16}F$

Electric Field



Assume there are point charges (sizes <<< r) P and Q placed r distance apart in a vacuum. Both charges create an electric field around them which ultimately is responsible for the force applied by the two on each other. The Electric Field around Q at position r is

$E(r) = \frac{kQ}{r^2}\hat{r}$

Where r is a unit vector of the distance r with respect to the origin. This value E(r) amounts to an electric field of each charge based on its position vector r. When another charge q is brought at a certain distance r to the charge Q, a force is exerted by Q equal to:

$F_Q = \frac{kQq}{r^2}\hat{r}$

Now, there is an equal and opposite force exerted on Q by q which is equal to:

$F_q = \frac{kqQ}{r^2}\hat{r}$ Hence, if q is a unit charge, the force applied is equal to field value.

Electric Field due to a System of Charges

If there is a system of charges q_1, q_2, ... q_n in space with position vectors r_1, r_2, ... r_n and the net effect of the Electric Charges are required to be calculated on a unit test charge q with position vector r placed inside the system, then it is attributed to a superimposition of Electric field values for all charges by Coulomb's Law:

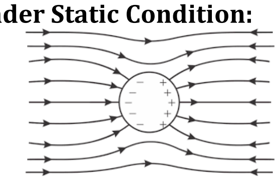
$E = E_1 + E_2 + ... + E_n$

$= kq_1/r_1^2 + kq_2/r_2^2 + ... + kq_n/r_n^2$

where $E_n(r_n)$ is the Electric Field value of charge n in the system with respect to position vector r_n. Here, E is a vector quantity and its value are attributed to change in the position of source charges.

Physical significance of electric field

Electric Field under Static Condition:



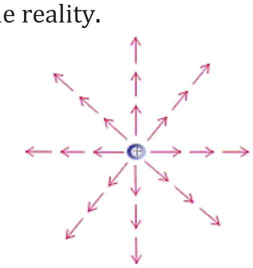
Static means 'at rest'. The charged bodies, under the static condition, experience an electric field surrounding them. The electric field is defined at every point and changes from point to point

Electric Field under Electromagnetic Non-static Condition:

This is the condition where the accelerated motion of the charge gives rise to electromagnetic waves and this propagates with a speed c passing on a force on another charge. Time-dependent magnetic and electric fields are connected with the transport of energy.

Electric field lines

The notion of the electrical field was first presented by the 19th-century physicist Michael Faraday. It was Faraday's understanding that the pattern of lines describing the electric field is an invisible reality.



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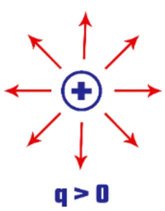
Since the electric field varies as the inverse of the square of the distance that points from the charge the vector gets shorter as you go away from the origin and they always point radially outwards. Connecting up these vectors to form a line is a nice way to represent the electric field. An electric field line is an imaginary line drawn in such a way that its direction at any point is the same as the direction of the field at that point. Field-line in general is a curve drawn in such a way that the tangent to it at each point in the direction of the net field at that point.

An electric field line is an imaginary line or curve drawn over an empty space region such that its tangent at each position, points in the direction of the electric field vector at this position.

The relative spacing between lines provides an indication of the electric field strength at that point. So, the magnitude of the field is indicated by the density of the lines. This means that electric field strength due to the charged body is more in the region where the density of field lines is high. In the region where the density of these lines is low, the electric field has lower strength. Magnitude is strong near the center where the electric field lines are close together, and it becomes weak as it move farther outwards, where they are relatively apart or they have less density. A field line or electric line of force can be considered as the path along which a small positive test charge would move if we let it move freely along the path.

Field Lines due to some charge configurations

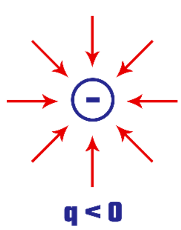
For a positive charge



Field lines of a single +ve charge point radially outwards

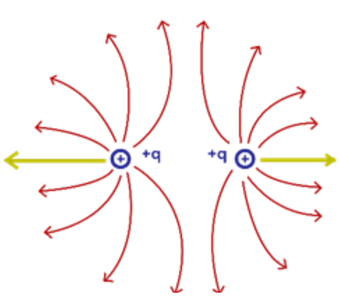
For a negative charge

For a negative charge, they are radially inwards as shown below in the figure

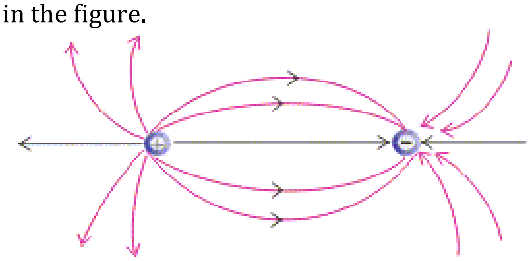


For Two Or More Charges

Field lines around the system of two +ive charges give a different picture and describe the mutual repulsion between them



Field lines around a system of a positive and -ve charge clearly show the mutual attraction between them as shown below in the figure.



Properties Of Electric Field Lines

Some important general properties of field lines are

1. Field lines start from a positive charge and end on a negative charge.
2. They are directed away from the positive electric charge and towards the negative electric charge. So, at any point tangent to field lines give the direction of the electric field at that point.
3. These lines leave or enter the charged surface normally.
4. Field lines never cross each other because if they do so then at the point of intersection there will be two directions of the electric field.
5. Electric field lines do not pass through a conductor; this shows that the electric field inside a conductor is always zero.

Electric flux

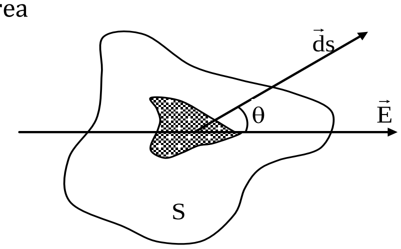
It is defined as the total number of lines of force passing normally through a curved surface placed in the field.

It is given by the dot product of and normal infinitesimal area $\vec{ds}$ integrated over a closed surface-

$$d\phi = \vec{E}.\vec{ds}$$

$$f = \oint \vec{E}.\vec{ds} = \oint Eds\cos\theta$$

where q = angle between electric field and normal to the area



if q = 0, f = Eds (maximum)

(b) if q = 90^0, □ = zero

Unit:

(a) Newton - metre^2 / coulomb

(b) Volt - meter

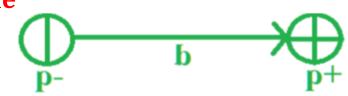
Dimension: $[M L^3 T^{-3} A^{-1}]$

Flux due to a positive change goes out of the surface while that due to negative change comes into the surface.

Flux entering is taken as positive while flux leaving is y taken as negative

Value of electric flux is independent of the shape and size of the surface.

Electric dipole



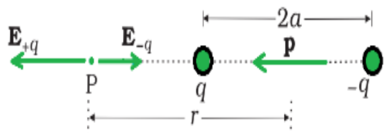
A pair of objects with equal and opposing charges separated by a large distance is referred to as an electric dipole. The first charge is assumed to be negative (-q), while the second charge remains positive (q). Electric dipoles in space are always directed from negative charge '-q' to positive charge 'q' by default. The dipole's center is the point where 'q' and '-q' meet.

The field of an electric dipole

Coulomb's law and the superposition principle may be used to calculate the electric field of a pair of charges (−q and q) at any point in space.

By applying the parallelogram law of vectors, the electric field at any general point P is determined by summing the electric fields E_{-q} due to the charge −q and E_{+q} due to the charge q.

For points on the axis



Suppose the point P be at distance r from the center of the dipole on the side of the charge q. Then electric field E_{-q} due to the charge −q can be expressed as,

$$E_{-q} = -\frac{q}{4\pi\varepsilon_0(r+a)^2}\hat{P}$$

where $\hat{P}$ is the unit vector along the dipole axis that is from −q to q. Similarly, Then electric field E+q due to the charge +q can be expressed as

$$E_{+q} = \frac{q}{4\pi\varepsilon_0(r-a)^2}\hat{P}$$

Now, the total field at P can be calculated by adding the electric fields E−q due to the charge −q and E+q due to the charge +q and can be expressed as

$$E = E_{+q} + E_{-q}$$

$$E = \frac{q}{4\pi\varepsilon_0(r-a)^2}\hat{P} + \left(-\frac{q}{4\pi\varepsilon_0(r+a)^2}\hat{P}\right)$$

$$E = -\frac{q}{4\pi\varepsilon_0(r-a)^2}\hat{P} - \frac{q}{4\pi\varepsilon_0(r+a)^2}\hat{P}$$

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

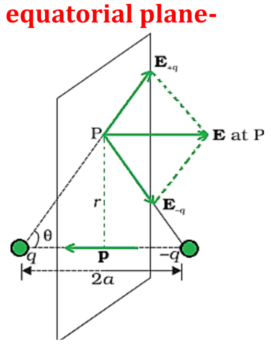
$$E = \frac{q}{4\pi\varepsilon_0}\left[\frac{4ar}{(r^2-a^2)^2}\right]\hat{P}$$

For r >> a, the above expression can be written as,

$$E = \frac{q}{4\pi\varepsilon_0}\left[\frac{4ar}{(r^2)^2}\right]\hat{P} \qquad E = \frac{q}{4\pi\varepsilon_0}\left[\frac{4ar}{r^4}\right]\hat{P}$$

$$E = \frac{q}{4\pi\varepsilon_0}\left[\frac{4ar}{r^3}\right]\hat{P}$$

For points on the equatorial plane-



Then, the electric field E+q due to the charge +q can be expressed as

$$E_{+q} = \frac{q}{4\pi\varepsilon_0}\frac{1}{r^2+a^2}$$

Similarly, then the electric field E_{-q} due to the charge −q can be expressed as,

$$E_{-q} = \frac{q}{4\pi\varepsilon_0}\frac{1}{r^2+a^2}$$

It is observed that the electric fields E_{-q} due to the charge −q and E_{+q} due to the charge +q and are equal. The E_{+q} and E_{-q} directions are displayed in the above-given figure. The components normal to the dipole axis clearly cancel out. Along the dipole axis, the components add up. The entire electric field is in the opposite direction of $\hat{P}$.

The above expression can be added as,

$$E = -\left(E_{+q} + E_{-q}\right)\cos\theta\,\hat{P}$$

$$E = -\frac{2q}{4\pi\varepsilon_0}\frac{a}{(r^2+a^2)^{\frac{3}{2}}}\hat{P}$$

At large distances (r >> a), the above expression can be written as,

$$E = -\frac{2q}{4\pi\varepsilon_0}\frac{a}{(r^2)^{\frac{3}{2}}}\hat{P}$$

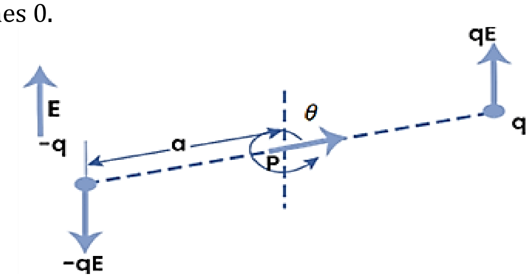
$$E = -\frac{2q}{4\pi\varepsilon_0}\frac{a}{r^3}\hat{P}$$

At great distances, it is evident in both cases that the dipole field does not involve q and a separately; it is dependent on the product qa. This hints at the meaning of the dipole moment. The dipole moment of an electric dipole is a vector quantity and it is symbol is p is defined by

$$p = q \times 2a\hat{P}$$

Dipole In A Uniform External Field

A uniform electric field has constant magnitude and fixed direction. Such a field is produced between the plates of a charged parallel plate capacitor.When two charges in a dipole are separated by some distance, the forces acting at different points result in a torque on the dipole. The torque tries to align the dipole with an electric field. Once aligned, the torque becomes 0.



Magnitude of torque

τ=qE x 2a sinθ

τ = 2qaE sinθ

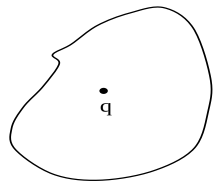
τ = pEsinθ.

The vector form of torque is the cross product of dipole moment and electric field.

Gauss law

This law states that electric flux f_E through any closed surface is equal to $1/e_0$ times the net charge 'q' enclosed by the surface i.e

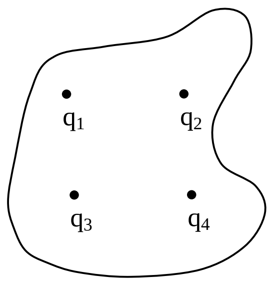
$$f_E = \oint \vec{E}.\vec{ds} = \frac{q}{\varepsilon_0}$$



Note

The closed surface can be hypothetical and then it is called a Gaussian surface.
If the closed surface enclosed a number of charges q_1, q_2 .... q_n etc. then

$$f = \oint \vec{E}.\vec{ds} = \frac{\Sigma q}{\varepsilon_0} = \frac{(q_1 + q_2 + ...q_n)}{\varepsilon_0}$$



Flux is -

Independent of distances between charges inside the surface and their distribution.

Independent of shape, size and nature of surface.

Gauss law is valid only for the vector fields which obey inverse square law

Gauss's and coulomb's law are comparable.

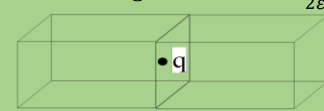
Note

(i) A charge q is placed at the centre of a cube, then
(a) Total flux through cube = $\frac{q}{\varepsilon_0}$

(b) Flux through each surface = $\frac{q}{6\varepsilon_0}$

(ii) A charge q is placed at the center of a face of a cube, then total flux through the cube = $\frac{q}{2\varepsilon_0}$

A second cube can be assumed adjacent to the first cube, total flux through both cubes
$= \frac{q}{\varepsilon_0}$, So flux through each cube = $\frac{q}{2\varepsilon_0}$

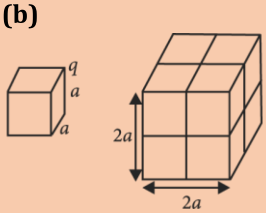


(iii) Now, q is placed at a corner then the flux will be $\frac{q}{8\varepsilon_0}$

Q. What is the flux through a cube of side a if a point charge of q is at one of its corners?

(a) $\frac{2q}{\varepsilon_0}$ (b) $\frac{q}{8\varepsilon_0}$ (c) $\frac{q}{\varepsilon_0}$ (d) $\frac{q}{2\varepsilon_0}6a^2$

Sol. **Ans. (b)**



Eight identical cubes are required so that the given charge q appears at the centre of the bigger cube.
Thus, the electric flux passing through the given cube is

$$\phi = \frac{1}{8}\left(\frac{q}{\varepsilon_0}\right) = \frac{q}{8\varepsilon_0}$$

Q. A charge Q is enclosed by a Gaussian spherical surface of radius R. If the radius is doubled, then determine the outward electric flux.

Sol. According to Gauss's law

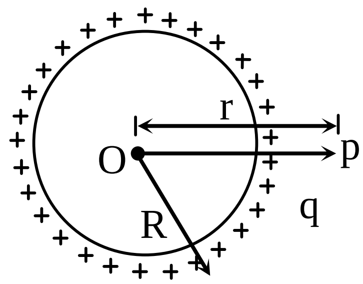
$$\phi_E = \frac{Q_{enclosed}}{\varepsilon_0}$$

If the radius of the Gaussian surface is doubled, the outward electric flux will remain the same. This is because electric flux depends only on the charge enclosed by the surface.

Application of Gauss's law

Electric field due to a charged conducting sphere/ Hollow conducting or insulating sphere.

In all the three types of spheres, charge resides only on the outer surface of the sphere in order to remain in minimum potential energy state.



Case: 1 OP = r ³ R

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

(s = surface charge density)

Case: 2 r = R $\quad \vec{E} = \frac{\sigma}{\varepsilon_0}\hat{r}$

Case: 3 r < R $\quad \vec{E} = 0$

i.e. At point interior to a conducting or a hollow sphere, electric field intensity is zero.

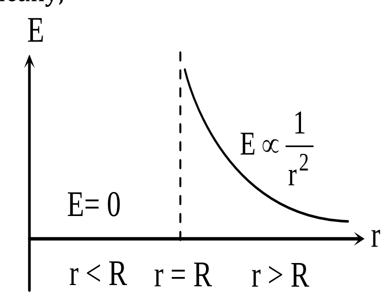
For points outside the sphere, it behaves like all the charge is present at the centre.

Intensity of electric field is maximum at the surface

Electric field at the surface is always perpendicular to the surface.

For points, near the surface of the conductor, E = perpendicular to the surface

Graphically,



Electric potential

Case: 1 r < R

$V_{in} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R} = \frac{\sigma R}{\varepsilon_0}$

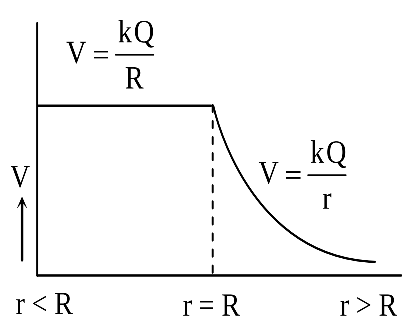
Case: 2 r = R

$V_{surface} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R} = \frac{\sigma R}{\varepsilon_0}$

Case: 3 r > R

$V_{out} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r} = \frac{\sigma R^2}{r}$

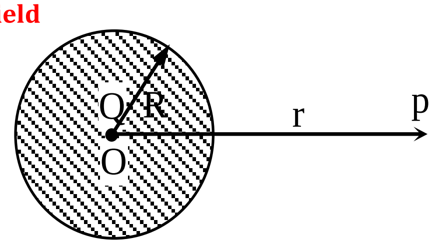
For points interior to a conducting or a hollow sphere, potential is same everywhere and equal to the potential at the surface.



Electric field due to solid insulating sphere

A charge given to a solid insulating sphere is distributed equally throughout its volume

Electric Field



Case: 1 r > R (point is outside the sphere)

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

Case: 2 r = R (point is at the surface)

$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R^2}\hat{r} = E_{max} = E_{surface}$

Case: 3 r < R (point is inside the sphere)

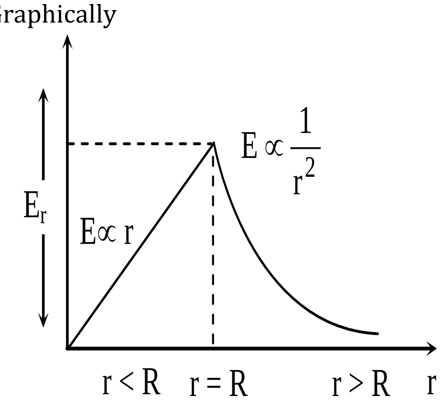
$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R^3} r\,\hat{r}$

$= \frac{\rho r}{3\varepsilon_0}$

E_{in} μ r

at r = 0, E = 0

Graphically



Again, for points outside the sphere, it behaves as all the charge is present at the centre

For points outside, it obeys inverse square law

Electric Potential

Case: 1 r > R

$V_{out} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$

Case: 2 r = R

$V_{surface} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R}$

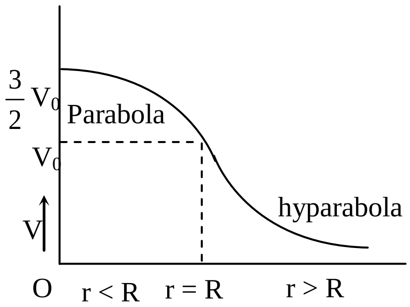
Case: 3 r < R

$V_{in} = \frac{1}{4\pi\varepsilon_0}\frac{Q(3R^2 - r^2)}{2R^3}$

$V_{centre} = \frac{3}{2}\frac{1}{4\pi\varepsilon_0}\frac{Q}{R}$

$V_{centre} = 3/2\ V_{surface}$

Graphically



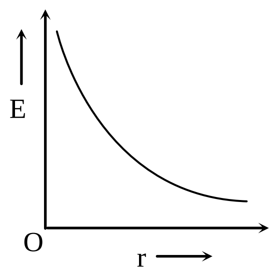
Electric field due to infinitely long charge

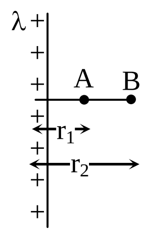
A long wire is given a line charge density l.

If wire is positively charged, direction of E will be away from the wire while for a negatively charged wire, direction of $\vec{E}$ will be towards the wire.

E at point p

$$\vec{E} = \frac{\lambda}{2\pi\varepsilon_0 r}\hat{r} \qquad \text{or } E = \frac{\lambda}{2\pi\varepsilon_0 r}$$





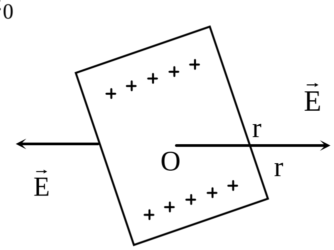
Potential difference between points A (r_1) & B(r_2) = $V_A - V_B = \frac{\lambda}{2\pi\varepsilon_0}\ln\left(\frac{r_2}{r_1}\right)$

If two charged wires (l_1) & (l_2) are kept parallel to each other at a distance 'd', then the force on unit length of any of the wire is:

$\frac{\lambda_1\lambda_2}{2\pi\varepsilon_0 d}$

Electric field at a point due to an infinite sheet of charge

If σ = surface charge density. Intensity at points near to the sheet = $\vec{E} = \frac{\sigma}{2\varepsilon_0}\hat{r}$



Direction of electric field is perpendicular to the sheet of charge.

Intensity of electric field does not depend upon the distance of points from the sheet for the points in front of sheet i.e. There is an equipotential region near the charged sheet.

Potential difference between two points A & B at distances r_1 & r_2 respectively is

$$V_A - V_B = \frac{\sigma}{2\varepsilon_0}(r_2 - r_1)$$

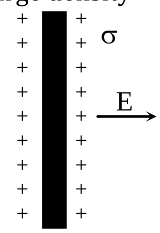
Electric field due to infinite charged metal sheet

Intensity at points near the sheet

$$\vec{E} = \frac{\sigma}{\varepsilon_0}\hat{r}$$

where

s = surface charge density



$\vec{E}$ is independent of distance of the point from the sheet and also of the area of sheet i.e. There is an equipotential region near the sheet.

Direction of electric field is perpendicular to the sheet.

Potential difference between two points A (r_1) and B (r_2) $(r_1 < r_2)$ near the sheet is

$$DV = V_A - V_B = \frac{\sigma}{\varepsilon_0}(r_2 - r_1)$$

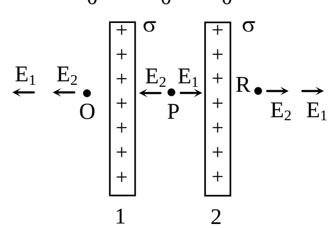
Electric field due to two infinite parallel plates of charge

Both plates have same type of charge

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

$$E_P = E_1 + E_2 = \frac{\sigma}{2\varepsilon_0} - \frac{\sigma}{2\varepsilon_0} = 0$$

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

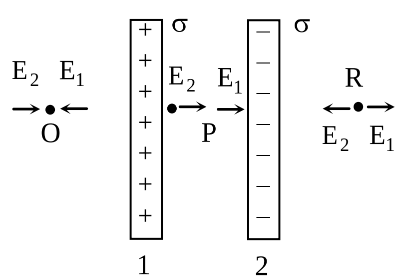


Two plates have opposite type of charge

$$E_O = E_1 + E_2 = \frac{\sigma}{2\varepsilon_0} - \frac{\sigma}{2\varepsilon_0} = 0$$

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

$$E_R = E_1 + E_2 = \frac{\sigma}{2\varepsilon_0} - \frac{\sigma}{2\varepsilon_0} = 0$$



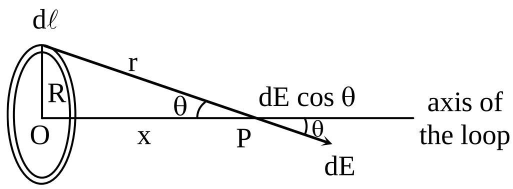
Note

In this case, we will have a uniform electric field between the two plates directed from positive to negative charged plate. Electric field intensity is zero elsewhere.

Electric field due to charged ring: Q charge is distributed over a ring of radius R.

Intensity of electric field at a distance x from the centre of ring along its axis -

$$E = \frac{1}{4\pi\varepsilon_0}\frac{Qx}{(R^2 + x^2)^{3/2}}$$



Intensity will be zero at the centre of the ring.

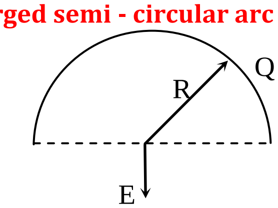
Intensity will be maximum at a distance $\frac{R}{\sqrt{2}}$ from the center and

$$E_{max} = \frac{2}{3\sqrt{3}}\cdot\frac{1}{4\pi\varepsilon_0}\cdot\frac{Q}{R^2}$$

Electric potential at a distance x from centre,

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{\sqrt{(x^2 + R^2)}}$$

Uniformly charged semi - circular arc



$E_{centre} = \frac{\lambda}{2\pi\varepsilon_0 R}$

where l = linear charge density = $\frac{Q}{\pi R}$

$V_{centre} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R}$

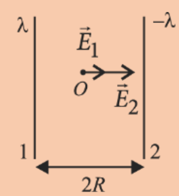
Q. Two parallel infinite line charges with linear charge densities $+\lambda$ C/m and $-\lambda$ C/m are placed at a distance of $2R$ in free space. What is the electric field mid-way between the two-line charges?

Sol. Electric field due to an infinite line charge, $E = \frac{\lambda}{2\pi\varepsilon_0 r}$

Net electric field at mid-point O,

$\vec{E}_0 = \vec{E}_1 + \vec{E}_2$

As, $E_1 = E_2 = \frac{\lambda}{2\pi\varepsilon_0 R} \therefore E_0 = 2E_1 = \frac{\lambda}{\pi\varepsilon_0 R}\,\mathrm{N\,C^{-1}}$

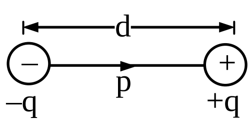


Q. A hollow insulated conduction sphere is given a positive charge of 10 μC. What will be the electric field at the centre of the sphere if its radius is 2 metres?

Sol. Field inside a conducting sphere = 0.

Electric dipole

A system consisting of two equal and opposite charges separated by a small distance is termed an electric dipole.



Na^+Cl^-, $H^+ Cl^-$ etc.

Dipole moment: The product of the magnitude of charges and distance between them is called the dipole moment.

(a) This is a vector quantity which is directed from negative to positive charge.

(b) Unit: Coulomb - metre (C-m)

(c) Dimension: $[M^0 L^1 T^1 A^1]$

(d) Dipole moment $\vec{p} = q\vec{d}$

Electric field due to a dipole

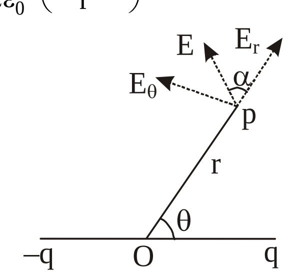
There are two components of electric field at any point

(a) E_r in the direction of $\vec{r}$

(b) E_q in the direction perpendicular to $\vec{r}$

$$E_r = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2P\cos\theta}{r^3}$$

$$E_q = \frac{1}{4\pi\varepsilon_0}\cdot\left(\frac{P\sin\theta}{r^3}\right)$$



Resultant

$$E = \sqrt{E_r^2 + E_\theta^2} = \frac{P}{4\pi\varepsilon_0 r^3}\sqrt{1+3\cos^2\theta}$$

Angle between the resultant $\vec{E}$ and $\vec{E}_r$, a is given by a

$$= \tan^{-1}\left(\frac{E_\theta}{E_r}\right) = \tan^{-1}\left(\frac{1}{2}\tan\theta\right)$$

If θ = 0, i.e point is on the axis -

$$E_{axis} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2P}{r^3}$$

q = 0, i. e. along the axis.

If q = 90º, i.e., point is on the line bisecting the dipole perpendicularly

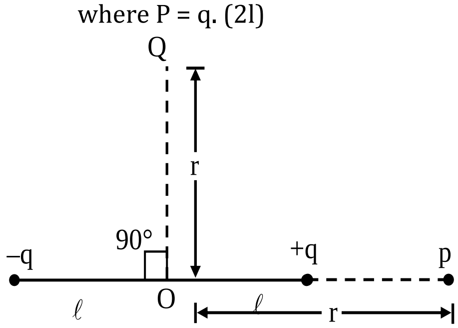
$$E_{equator} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{P}{r^3}$$

So, $E_{axis} = 2E_{equator}$ (for same r)

$$E_{axis} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2Pr}{(r^2-\ell^2)^2}$$

$$E_{equator} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{P}{(r^2+\ell^2)^{3/2}}$$

where P = q. (2l)



$$V = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q(2\ell)\cos\theta}{r^2}$$

$$= \frac{1}{4\pi\varepsilon_0}\cdot\frac{P\cos\theta}{r^2} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{\vec{P}.\vec{r}}{r^2}$$

$$= \frac{1}{4\pi\varepsilon_0}\cdot\frac{\vec{P}.\hat{r}}{r^3}$$

where q is the angle between $\vec{P}$ and $\vec{r}$.

V can also be written as

$$V = -\frac{1}{4\pi\varepsilon_0}\vec{P}.\nabla\left(\frac{1}{r}\right) \text{because } \nabla\left(\frac{1}{r}\right) = -\frac{\hat{r}}{r^2}$$

If q = 0, $V_{axis} = \dfrac{P}{4\pi\varepsilon_0 . r^2}$

If q = 90º, $V_{equator} = 0$

Here we see that V = 0 but E ¹ 0 for points at equator

Again, if r >> 2l is not true and d = 2l,

$$V_{axis} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{P}{(r^2-\ell^2)}$$

$V_{equator} = 0$

Note

(i) This is not essential that at a point, where E = 0, V will also be zero there e.g., inside a uniformly charged sphere, E = 0 but V ¹ 0

(ii) Also, if V = 0, it is not essential for E to be zero e.g., in equatorial position of dipole
V = 0, but E ¹ 0

Electric dipole in an electric field - uniform electric field

When an electric dipole is placed in a uniform electric dipole, a torque acts on it

which subjects the dipole to rotatory motion. This t is given by t = PE sinq or

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

Potential energy of the dipole

$$U = -\text{ PE cos q} = -\vec{P}.\vec{E}$$

Cases:

(a) If q = 0º, i.e., $\vec{P} || \vec{E}$, t = 0 and U = – PE, dipole is in the minimum potential energy state and no torque acting on it and hence it is in the stable equilibrium state.

(b) For q = 180º, i.e., $\vec{P}$ and $\vec{E}$ are in opposite direction, then t = 0 but U = PE which is maximum potential energy state. Although it is in equilibrium but it is not a stable state and a slight perturbation can disturb it.

(c) q = 90^0, i.e., $\vec{P} \perp \vec{E}$, then
t = PE (maximum) and U = 0

Note

(a) There is no net force acting on the dipole in a uniform electric field.

(b) If dipole is placed in a non-uniform electric field, it performs rotatory as well as translator motion because now a net force also acts on the dipole along with the torque. (Important)

Work done in rotating on electric dipole in an electric field

(i) Work done in rotating the dipole from q_1 to q_2 in a uniform electric field

$$W = PE\ (\cos q_1 - \cos q_2)$$

Force on the surface of a charged

If surface charge density on a surface is s, then electric field intensity at a point near this surface is $\frac{\sigma}{\varepsilon_0}$.

When a conductor is charged then it's entire surface experiences an outward force perpendicular to the surface. The force per unit area of the charged surface is called as the electrical pressure,

$$P_{electrical} = \frac{\sigma^2}{2\varepsilon_0} N/m^2.$$

The direction of this force is perpendicular to the surface.

Energy associated with the electric field

(i) The energy stored per unit volume around a point in an electric field E is given by

$U = \frac{1}{2} e_0 E^2$ This is also called energy density

(ii) If in place of vacuum some medium is present then $U = \frac{1}{2} e_0 e_r E^2$.

Drop of a charged liquid -

If n identical drops each having a charge q and radius r coalesce to form a single large drop of radius R and charge Q, then

(a) Charge will be conserved i.e., nq = Q

(b) Volume will be conserved i.e.

$n. \frac{4}{3} pr^3 = \frac{4}{3} pR^3$ or $R = n^{1/3} r$ (c) Potential of each small drops = $V = \frac{1}{4\pi\varepsilon_0} . \frac{q}{r}$

(d) Potential of large drop = V'

$V' = \frac{1}{4\pi\varepsilon_0} \frac{Q}{R} = V' = n^{2/3} V$

(e) Electric field at surface of small drop $E = \frac{1}{4\pi\varepsilon_0} . \frac{q}{r^2}$

(f) Electric field at surface of large drop = E'

$E' = \frac{1}{4\pi\varepsilon_0} . \frac{Q}{R^2}$

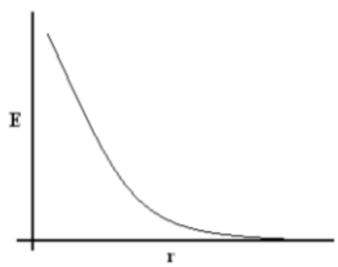
$E' = n^{1/3} z$

SUMMARY

Like Charges and Unlike Charges:

Like charges repel and unlike charges attract each other.

- **Conductors and Insulators:**
  Conductors allow movement of electric charge through them, insulators do not.
- Quantization of Electric Charge: It means that total charge (q) of a body is always an integral multiple of a basic quantum of
  charge (e)
  $$q = ne$$
  where n = 0, ±1, ±2, ±3, ...
- **Additivity of Electric Charges:**
  Total charge of a system is the algebraic sum of all individual charges in the system.
- **Conservation of Electric Charges:**
  The total charge of an isolated system remains uncharged with time.
- **Superposition Principle:**
  It is the properties of forces with which two charges attract or repel each other are not affected by the presence of a third (or more) additional charge(s).
- **The Electric Field E at a Point due to a Charge Configuration:** It is the force on a small positive test charges q placed at the point divided by a magnitude



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

It is radially outwards from q, if q is positive and radially inwards if q is negative.

E at a point varies inversely as the square of its distance from *Q*, the plot of *E* versus *r* will look like the figure given below.

Coulomb's Law:

The mutual electrostatic force between two point charges q_1 and q_2 is proportional to the product q_1q_2 and inversely proportional to the square of the distance r_{21} separating them.

$$\vec{F}_{21}(\,force\,\text{on } q_2 \text{ due to } q_1 = \frac{k(q_1q2)}{r_{21}^2}\hat{r}_{21}$$

Where $\hat{r}_{21}$ is a unit vector in the direction from q_1 to q_2 and

$k = \frac{1}{4\pi\varepsilon_0}$ is the proportionality constant.

An Electric Field Line:

It is a curve drawn in such a way that the tangent at each point on the curve gives the direction of electric field at that point.

Important Properties of Field Lines:

These are:

(i) Field lines are continuous curves without any breaks.

(ii) Two field lines cannot cross each other.

(iii) Electrostatic field lines start at positive charges and end at negative charges – they
cannot form closed loops.

- **Electric Field at a Point due to Charge q:**
  $$\vec{E} = \frac{\vec{F}}{q}$$
- **Electric Field due to an Electric Dipole in its Equatorial Plane at a Distance r from the Centre:**
  $\vec{E} = \frac{-p}{4\pi\varepsilon_0}\frac{1}{(a^2+r^2)^{\frac{3}{2}}}$
  $\cong \frac{-p}{4\pi\varepsilon_0}, for$r>>a
- **Electric Field due to an Electric Dipole on the Axis at a Distance r from the Centre:**
  $E = \frac{2pr}{4\pi\varepsilon_0(r^2-a^2)^2}$
  $\cong \frac{2p}{4\pi\varepsilon_0 r^3}, for$r>>a
- **A Dipole Placed in Uniform Electric Field E experiences:**
  Torque $\vec{\tau}$,
  $\vec{\tau} = \vec{p}x\vec{E}$
- **The Electric Flux:**
  $\phi = \int d\phi = \int \vec{E}.d\vec{s}$is a 'dot' product, hence it is scalar.
  $\Delta\phi$ is positive for all values of $\theta < \frac{\pi}{2}$
  $\Delta\phi$ is negative for all values of $\theta > \frac{\pi}{2}$
- **Gauss's Law:**
  The flux of electric field through any closed surface S is 1/ε0 times the total charge enclosed by S.
  $\phi = \int \vec{E}.d\vec{s} = \frac{q}{\varepsilon_0}$
- Electric field outside the charged shell is as though the total charge is concentrated at the centre. The same result is true for a solid sphere of uniform volume charge density.
- The electric field is zero at all points inside a charged shell.
- **Electric field E, due to an infinitely long straight wire of uniform linear charge density λ:**
  $E = \frac{\lambda}{2\pi\varepsilon_0 r}.\hat{n}$
  where r is the perpendicular distance of the point from the wire and is the radial unit vector in the plane normal to the wire passing through the point.

- **Electric field E, due to an infinite thin plane sheet of uniform surface charge density σ:**

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

Where $\hat{n}$ is a unit vector normal to the plane, outward on either side.

- **Electric field E, due to thin spherical shell of uniform surface charge density σ:**

$$E = \frac{q}{4\pi\varepsilon_0 r^2}.\hat{r}(r \geq R)$$

$$\mathrm{E} = 0(r < R)$$

where r is the distance of the point from the centre of the shell and R the radius of the shell, q is the total charge of the shell & $q = 4\pi R^2\sigma$.

- Electric field E along the outward normal to the surface is zero and σ is the surface charge density. Charges in a conductor can reside only at its surface. Potential is constant within and on the surface of a conductor. In a cavity within a conductor (with no charges), the electric field is zero.

MIND MAP

Electric Charges & Fields

Quantization of charge

All observable charges must be integral multiple of *e*. i.e. $Q = ne$ where *n* = integers

- Two kinds of charges + ve and – ve
- S.I unit is coulomb (C)
  1 C = charge flowing through
- a wire in 1 sec if current in it is 1A
  $1e = 1.602 \times 10^{-19}$ C

Conservation of charge

It is not possible to create or destroy net charge of an isolated system.

Electric flux

$\Delta\phi = \vec{E}.\Delta\vec{S}$, $\Delta\vec{S}$ = area vector

E = electric field

$\phi = \int \vec{E}.\vec{ds}$

Gauss's Theorem

$\oint \vec{E}.\vec{ds} = q_{in}/\varepsilon_0 = \phi$

where, q_{in} = net charge enclosed

ϕ = flux through a closed surface

Application of Gauss's Law

- Field due to linear charge distribution
  $E = \lambda/2\pi\,\varepsilon_0 r$,
  λ = linear charge density
- Field due to a plane sheet of charge
  $E = \sigma/2\varepsilon_0$,
  σ = charge per unit area
- Field due to a charged conducting plate
  $E = \sigma/\varepsilon_0$,
  σ = charge per unit area
- Field inside a conductor = 0
- Electric field due to a thin spherical shell at a point
  Outside the shell, $E = Q/4\pi\varepsilon_0 r^2$
  Inside the shell, $E = 0$
  On the surface $E = Q/4\pi\varepsilon_0 R^2$
- Electric field due to uniformly charged share at an
  Outside point
  $E = Q/4\pi\varepsilon_0 r^2$
  Internal point
  $E = Qr/4\pi\varepsilon_0 R^3$
  On the surface
  $E = Q/4\pi\varepsilon_0 R^2$

Electric field due to uniformly charged sphere at an

- Outside point
  $E = Q/4\pi\varepsilon_0 r^2$
  Internal point
  $E = Qr/4\pi\varepsilon_0 R^3$
- On the surface
  $E = Q/4\pi\varepsilon_0 R^2$

Electric charges

In 1985, Charles Augustin de Coulomb gives coulomb's law

Coulomb's Law

- Force between two charged particle

$\vec{F} = \dfrac{k\,q_1\,q_2\,\vec{r}}{r^3} = \dfrac{kq_1\,q_2\,\hat{r}}{r^2}$, force is attractive when q_1 and q_2 are of opposite sign, otherwise repulsive

$|\vec{F}| = \dfrac{k\,q_1\,q_2}{r^2}$

$k = \dfrac{1}{4\pi\varepsilon_0} \approx 9\times10^9\,Nm^2C^{-2}$

- Force between multiple charges

$\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} + \vec{F}_{15} + \;= \dfrac{q_1}{4\pi\varepsilon_0}\sum_{i=2}^{n}\dfrac{q_i}{r_{1i}^2}\,\hat{r}_{1i}$

where $\hat{r}_{1i}$ is the unit vector along charge particle under consideration

$\hat{r}_{1i}$ = distance between I and i^{th} particle

"The electric force with which two charges attracts or repel one another are not affected by the presence of other charges". It is known as Superposition Principle.

Electric Field

Electric field lines

- Always normal to conducting surface
- Lines originating from +ve charge
- Terminating at –ve charge
- Never intersect each other
- Never form closed loop
- Are imaginary lines.

Electric field due to point charge

$\vec{E} = \dfrac{\vec{F}}{q} \quad = k\,\dfrac{Q}{r^2}$ (N/C)

$\because$ unit = N/C

- Due to discrete distribution of charges
  $\vec{E} = \sum_{i}^{n}\vec{E_i}$
- Due to continuous distribution of charges
  $\vec{E} = k\int\dfrac{dQ}{r^3}\vec{r}$
  $|\vec{E}| = k\int\dfrac{dQ}{r^2}$

Electric Dipole, $\vec{p} = q\vec{d}$

Electric field due to dipole at axial position

$\vec{E} = \dfrac{1}{4\pi\,\varepsilon_0}\left(\dfrac{2P}{r^3}\right)\hat{r}$

Electric field due to dipole at equatorial position

$|E| = \dfrac{1}{4\pi\,\varepsilon_0}\left(\dfrac{P}{r^3}\right)$

Torque on an electric dipole placed in an electric field $(\vec{E})$

$\vec{\tau} = \vec{p}\times\vec{e} = p\,E\sin\theta$

PRACTICE EXERCISE

MCQ

Q1. An electron falls a distance of 4 cm in a uniform electric field of magnitude 5×10^4 N/C. The time taken by electron in falling will be-

(a) 2.99×10^{-7} s (b) 2.99×10^{-8} s
(c) 2.99×10^{-9} s (d) 2.99×10^{-10} s

Q2. If the sizes of charged bodies are very small compared to the distances between them, we treat them as __________.

(a) Zero charges (b) Point charges
(c) Single charge (d) No charges

Q3. A small sphere carrying a charge 'q' is hanging in between two parallel plates by a string of length L. Time period of pendulum is T_0. When parallel Plates are charged, the time period changes to T. the ratio $\frac{T}{T_0}$ is equal

(a) $\left(\frac{g+\frac{qE}{m}}{g}\right)^{1/2}$ (b) $\left(\frac{g}{g+\frac{qE}{m}}\right)^{3/2}$
(c) $\left(\frac{g}{g+\frac{qE}{m}}\right)^{1/2}$ (d) $\left(\frac{g}{g+\frac{qE}{m}}\right)^{5/2}$

Q4. The force per unit charge is known as __________.

(a) Electric current
(b) Electric potential
(c) Electric field
(d) Electric space

Q5. An electric dipole, consisting of two opposite charges of 2×10^{-6} C each separated by a distance 3 cm is placed in and electric field of $2 \times 10^{-6}\ C$ each separated by a distance 3 cm is placed in an electric field of $2 \times 10^5\ N/C$. Torque acting on the dipole is

(a) $12 \times 10^{-1}\ N-m$
(b) $12 \times 10^{-2}\ N-m$
(c) $12 \times 10^{-3}\ N-m$
(d) $12 \times 10^{-4}\ N-m$

Q6. What is the dielectric constant of a metal?

(a) -1 (b) 0
(c) 1 (d) Infinite

Q7. There is an electric field E in X-direction. If the work done on moving a charge of 0.2 C through a distance of 2 m along a line making an angle 60^0 with x-axis is 4 J, then what is the value of E?

(a) 3 N/C (b) 4 N/C
(c) 5 N/C (d) 20 N/C

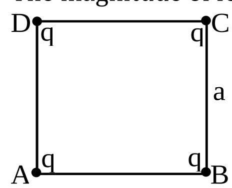
Q8. The property which differentiates two kinds of charges is called __________.

(a) Equality of charge
(b) Polarity of charge
(c) Fraction of charge
(d) None of the option

Q9. The bob of a pendulum carries an electric charge of 39.2×10^{-10} coulomb in a horizontal electric field of 20×10^3 V/m and it is at rest. The angle made by the pendulum with the vertical will be, if the mass of pendulum is 8×10^{-6} kg and g = 9.8 m/s² -

(a) 27º (b) 45º
(c) 87º (d) 127º

Q10. A square of side 'a' has equal charge 'q' at its corners. The magnitude of force at B will be-



(a) $\frac{1}{2}\frac{kq^2}{a^2}(1+2\sqrt{2})$
(b) $\frac{1}{2}\frac{k^2q^2}{a^2}$
(c) $\frac{4kq^2}{a^2}$
(d) none of these

Q11. ———— gives the information on field strength, direction, and nature of the charge.

(a) Electric current
(b) Electric flux
(c) Electric field
(d) Electric potential

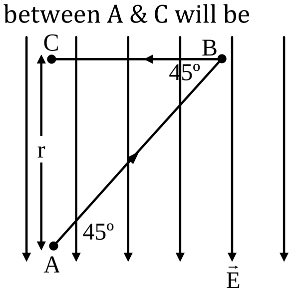
Q12. An electron falls a distance of 4 cm in a uniform electric field of magnitude 5×10^4 N/C. The time taken by electron in falling will be-

(a) 2.99×10^{-7} s (b) 2.99×10^{-8} s
(c) 2.99×10^{-9} s (d) 2.99×10^{-10} s

Q13. What happens when a glass rod is rubbed with silk?

(a) gains protons from silk
(b) gains electrons from silk
(c) gives electrons to silk
(d) gives protons to silk

Q14. In the adjacent figure a unit positive charge moves along the path ABC in an electric field E. The potential difference between A & C will be



(a) 0
(b) Er
(c) Er/2
(d) Er/4

Q15. Sphere of radius 4 cm is suspended inside a hollow spherical conductor of radius 6 cm concentrically. The small sphere is charged upto 3 e.s.u and the outer surface is connected to earth. The potential difference between the spheres will be-

(a) 36 e.s.u. (b) 54 e.s.u.
(c) 30 e.s.u. (d) 0.25 e.s.u.

Q16. An electron is placed in an electric field of intensity 104 Newton per Coulomb. The electric force working on the electron is

(a) 0.625×10^{13} Newton (b) 0.625×10^{-15} Newton
(c) 1.6×10^{15} Newton (d) 1.6×10^{-15} Newton

Q17. Which of the following is false about Electrostatic field lines?

(a) Field lines start from positive charges and end at negative charges.
(b) If there is a single positive charge, field lines will end at infinity.
(c) Two field lines can never cross each other
(d) Electrostatic field lines form closed loops.

Q18 The magnitude of electric force experienced by a charged particle in an electric field depends on

(a) charge of the particle
(b) the velocity of the particle
(c) the direction of the electric field
(d) mass of the particle

Q19. A hollow metal ball-carrying an electric charge produces no electric field at points:

(a) Outside the sphere (b) On its surface
(c) Inside the sphere (d) Only at the center

S20. The electrostatic force acting per unit positive test charge at a location is a measure of the intensity of:

(a) Electric potential (b) Electric field
(c) Coulomb force (d) Gravity

Q21. A charge q is placed at the centre of the line joining two equal charges Q. The system of the three charges will be in equilibrium if q is equal to

(a) $-Q/4$ (b) $Q/4$
(c) $-\frac{Q}{2}$ (d) $Q/2$

Q22. A body can be negatively charged by

(a) giving excess of electrons to it
(b) removing some electron from it
(c) giving some protons to it
(d) removing some neutrons from it.

Q23. Which of the following is not a property of field lines?

(a) Field lines are continuous curves without any breaks
(b) Two field lines cannot cross each other
(c) Field lines start at positive charges and end at negative charges
(d) They form closed loops

Q24. Gauss's law is valid for

(a) Any closed surface
(b) Only regular closed surfaces
(c) Any open surface
(d) Only irregular open surfaces.

Q25. When air is replaced by a medium of dielectric constant K, the force of attraction between two charges separated by a distance r

(a) decreases K times
(b) remains unchanged
(c) increases K times
(d) increases K^{-2}

ASSERTION AND REASONING

Directions: These questions consist of two statements, each printed as Assertion and Reason. While answering these questions, you are required to choose any one of the following four responses.

(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are trug and but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false, but R is true

Q1. Assertion The charge on anybody can be increased or decreased in terms of e
Reason - Quantization of charge means that the charge of a body is integral multiple of e

Q2. Assertion - When we rub a glass rod with Silk, the rod gets negatively charged and the Silk gets positively charged
Reason - On rubbing, electrons from Silk cloth move to the glass rod

Q3. Assertion - Consider two identical charges placed distance 2d apart, along the x-axis. The equilibrium of a positive test charge placed at the point O midway between them is stable for displacements along the x-axis
Reason- Force on test charge is zero

Q4. Assertion - Coulomb's force is the dominating force in the universe
Reason - Coulomb's force is weaker then the gravitational

Q5. Assertion - On going away from a point charge or a small electric dipole, electric field decreases at the same rate in both the cases
Reason - Electric field is inversely proportional to cube of distance from the charge of an electric dipole

VERY SHORT ANSWER QUESTIONS

Q1. What is the electric flux through a cube of side 1 cm which encloses an electric dipole?

Q2. Why do the electrostatic field lines not form closed loops?

Q3. 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.

Q4. Two metallic spheres A and B kept on insulating stands are in contact with each other. A positively charged rod P is brought near the sphere A as shown in the figure. The two spheres are separated from each other, and the rod P is removed. What will be the nature of charges on spheres A and B?

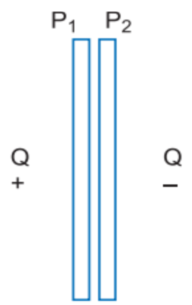
Q5. The dimensions of an atom are of the order of an Angstrom. Thus there must be large electric fields between the protons and electrons. Why, then is the electrostatic field inside a conductor zero?

SHORT ANSWER QUESTIONS

Q1. (a) An electrostatic field line is a continuous curve. That is, a field line cannot have sudden breaks. Why is it so?
(b) Explain why two field lines never cross each other at any point.

Q2. (a) Define electric flux. Write its SI unit.
(b) A spherical rubber balloon carries a charge that is uniformly distributed over its surface. As the balloon is blown up and increases in size, how does the total electric flux come out of the surface change? Give reason.

Q3. Figure shows two large metal plates P_1 and P_2, tightly held against each other and placed between two equal and unlike point charges perpendicular to the line joining them.



(i) What will happen to the plates when they are released?
(ii) Draw the pattern of the electric field lines for the system.

Q4. Represent graphically the variation of electric field with distance, for a uniformly charged plane sheet.

Q5. (a) Define electric flux. Write its SI unit. (b) "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.

CASE STUDY QUESTIONS

Q1. A Faraday cage or Faraday Shield is an enclosure made of a conducting material. The fields within & conductor cancel out with any external fields, so the electric field within the enclosure is zero.
These Faraday cage act as a big hollow conductor; you can put things in it to shield them from electric fields. Any electrical shock cage receives, pass harmlessly around the outside of the cage.

(i) Which of the following material can be made Faraday cage
(a) Plastic
(b) Glass
(c) Copper
(d) Wood

(ii) Example of real-world Faraday cage is
(a) Cars (b) Plastic box
(c) Lightning rod (d) Metal rod

(iii) What is the electrical force inside a Faraday cage when it is struck by lightning
(a) The same as the lightning
(b) Half that of the lightning
(c) Zero
(d) A quarter of the lightning

(iv) An isolated point charge + q is placed inside a Faraday cage. Its surface must have charge equal to
(a) Zero (b) +q
(c) -q (d) +20

Q2. A system of closely spaced electric charge forms a continuous charge distribution. To find the field of a continuous charge distribution, we divide the charge into infinitesimal charge elements. Each infinitesimal charge element is then considered as a point charge and electric field dE is determined due to this charge at given point. The net field at the given point is the summation of fields of all the elements i.e., $E = \int dE$

(i) How many electrons must be added to an isolated spherical conductor of radius 20 cm to produce an electric 1000 N/C just outside the surface?
(a) 2.77×10^{20} (b) 2.77×10^{10}
(c) 1.77×10^{10} (d) 5.4×10^{10}

(ii) A circular annulus of inner radius r and outer radius R has a uniform charge density 'a'. What will be the total charge on the annulus?
(a) a $(R2-r^2)$ (b) $\pi a (R^2-r^2)$
(c) a (R-r) (d) $\pi a R2$

(iii) What is the dimension of linear charge density?
(a) $[ATL^{-1}]$ (b) $[AT\ ^{1}L]$
(c) [ATL] (d) $[A^{-1}T^{-1}L]$

Q3. Microwave oven works on the principle of torque acting on an electric dipole. The food we consume has water molecules which are permanent electric dipoles. Oven produces microwaves that are oscillating electromagnetic field and produce torque on each water molecules. Due to this torque on ech water molecule, molecules rotate very fast and produce thermal energy. Thus, heat generated is used to heat the food.

(i) An electric dipole is placed at an angle of 300 to a uniform electric field. The dipole will experience a torque as well as & translational force.
(a) a torque as well as & translational force.
(b) a torque only

(c) a translational force only in the direction of the field 4. a translational force only in a direction normal to

(d) direction of the field

(ii) An electric dipole is placed in a nonuniform electric field, what acts on it?

(a) only torque (b) only force

(c) both 1 and 2 (d) none of these

(iii) An electric dipole of moment p in placed in a uniform electric field E. The maximum torque experienced by the dipole is

(a) pE (b) p/E

(c) E/p (d) p.E

(iv) Let Ea be the electric field due to a dipole in its axial plane distant I and let Eq be the field in the equatorial plane distant 1. The relation between Ea and Eq is

(a) Ea = Eq (b) Ea = 2Eq

(c) Eq = 2Ea (d) Ea = 3Eq

Q4. Coulomb's law states that the electrostatic force of attraction or repulsion acting between two stationary point charges is given by-

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

where F denotes the force between two charges q_1 and q_2 separated by a distance r in free space, ε_0 is a constant known as permittivity of free space. Free space is vacuum and may be taken to be air practically. If free space is replaced by a medium, then ε_0 is replaced by (ε_0k) or ($\varepsilon_0\varepsilon_r$) where k is known as dielectric constant or relative permittivity.

(i) In coulomb's law, , $F = k\frac{q_1 q_2}{r^2}$ then on which of the following factors does the proportionality constant k depends?

(a) Electrostatic force acting between the two charges

(b) Nature of the medium between the two charges

(c) Magnitude of the two charges

(d) Distance between the two charges

(ii) Dimensional formula for the permittivity constant e0of free space is

(a) $[M L^{-3} T^4 A^2]$ (b) $[M^{-1} L^3 T^2 A^2]$

(c) $[M^{-1} L^{-3} T^4 A^2]$ (d) $[M L^{-3} T^4 A^{-2}]$

(iii) The force of repulsion between two charges of 1 C each, kept 1 m apart in vacuum is

(a) $\frac{1}{9\times10^9}$N (b) 9×10^9N

(c) 9×10^7 N (d) $\frac{1}{9\times10^{12}}$N

NUMERICAL TYPE QUESTIONS

Q1. Two isolated metal spheres A and B have radii R and 2R respectively, and same charge q. Find which of the two spheres have greater energy density just outside the surface of the spheres.

Q2. Two small balls having equal charges Q, are suspended from a hook with two insulating threads each of length L. This arrangement is carried in the space, where there is no gravitation. Then find the tension in each string.

Q3. Two particles A and B having masses equal and charges q and 4q. If these are accelerated from rest through same potential difference, then what will be the ratio in their speeds?

Q4. A point charge of 2.0 μC is at the centre of a cubic Gaussian surface 9.0 cm on edge. What is the net electric flux through the surface?

Q5. A point charge causes an electric flux of – 1.0 × 10^3 Nm^2 C^{-1} to pass through a spherical surface of 10.0 cm radius centred on the charge.

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

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

Q6. A uniformly charged conducting sphere of 2.4 m diameter has a surface charge density of 80.0 μC /m^2

(a) Find the charge on the sphere.

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

Q7. How many electrons must be removed from an electrically neutral metal plate to give it a positive charge of 1 × 10^{-7} coulomb?

Q8. The surface charge density of a thin charged disc of radius R is σ. The value of the electric field at the centre of the disc is $\frac{\sigma}{2\,\epsilon_0}$. With respect to the field at the centre, then determine the reduced electric field along the axis at a distance R from the centre of the disc.

Q9. A surface has the area vector $\vec{A} = (2\hat{\imath} + \hat{\jmath})m^2$. What will be the flux of an electric field through it if the field is $\vec{E} = 4\hat{\imath}\frac{V}{m}$.

Q10. Two equally charged, identical metal spheres A and B repel each other with a force 'F'. The spheres are kept fixed with a distance 'r' between them. A third identical, but uncharged sphere C is brought in contact with A and then placed at the midpoint of the line joining A and B. Determine the magnitude of the net electric force on C.

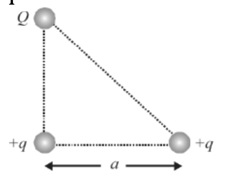
Q11. A cup contains 250 g of water. Determine the number of negative charges present in the cup of water.

Q12. The electric potential V is given as a function of distance x (meter) by V = ($5x^2$–10x–9) volts. Then find the value of the electric field at x = 1 m.

HOMEWORK EXERCISE

MCQ

Q1. Three charges $Q, +q$ and $+q$ are placed at the vertices of right-angled isosceles triangle as shown in the figure. The net electrostatic energy of the configuration is zero if Q is equal to



(a) $\frac{-q}{1+\sqrt{2}}$ (b) $\frac{-2q}{2+\sqrt{2}}$
(c) $-2q$ (d) $+q$

Q2. Three charges of equal value 'q' are placed at the vertices of an equilateral triangle. What is the net potential energy, if the side of equilateral Δ is?

(a) $\frac{1}{4\pi\epsilon_0}\frac{q^2}{l}$ (b) $\frac{1}{4\pi\epsilon_0}\frac{2q^2}{l}$
(c) $\frac{1}{4\pi\epsilon_0}\frac{3q^2}{l}$ (d) $\frac{1}{4\pi\epsilon_0}\frac{4q^2}{l}$

Q3. Two equal charges q are placed at a distance of $2a$ and a third charge $-2q$ is placed at the midpoint. The potential energy of the system is

(a) $\frac{q^2}{8\pi\epsilon_0 a}$ (b) $\frac{6q^2}{8\pi\epsilon_0 a}$
(c) $-\frac{7q^2}{8\pi\epsilon_0 a}$ (d) $\frac{9q^2}{8\pi\epsilon_0 a}$

Q4. The intensity of the electric field at any point on the surface of a charged conductor is
(a) zero
(b) perpendicular to surface
(c) tangential to surface
(d) infinite

Q5. In an electric field E directed downwards a proton of charge e will experience a ________.
(a) the upward force of magnitude eE
(b) the downward force of magnitude e/E
(c) the upward force of magnitude e/E
(d) the downward force of magnitude eE

Q6. A hollow metal ball-carrying an electric charge produces no electric field at points:
(a) Outside the sphere
(b) On its surface
(c) Inside the sphere
(d) Only at the center

Q7. If the potential at every point on a conductor is the same, then
(a) Electric field lines of force may begin or end on the same conductor
(b) No electric field lines of force may begin or end on the same conductor
(c) The electric field intensity inside the conductor is non-zero
(d) None of the above

Q8. The force experienced by a unit positive test charge placed at a point is called
(a) The magnetic field at that point
(b) The gravitational field at that point
(c) The electrical field at that point
(d) The nuclear field at that point

Q9. The SI unit of the electric field is:
(a) Cm-2
(b) Am-1
(c) Vm-1
(d) Cm-1

Q10. The force experienced by a charged particle of -6 C in the external electric field is 60 N towards the north. The electric field intensity will be:
(a) 10 N/C towards the north
(b) 10 N/C towards the south
(c) 6 N/C towards the north
(d) 6 N/C towards south

VERY SHORT ANSWER QUESTIONS

Q1. Draw the pattern of electric field lines, when a point charge –Q is kept near an uncharged conducting plate.

Q2. Why do the electrostatic field lines not form closed loops?

Q3. The dimensions of an atom are of the order of an Angstrom. Thus, there must be large electric fields between the protons and electrons. Why, then is the electrostatic field inside a conductor zero?

Q4. What is the electric flux through a cube of side 1 cm which encloses an electric dipole?

Q5. Why do the electric field lines never cross each other?

SHORT ANSWER QUESTIONS

Q1. A spherical conducting shell of inner radius r1 and outer radius r2 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>r2 from the centre of the shell.

Q2. Why are electric field lines perpendicular at a point on an equipotential surface of a conductor?

LONG ANSWER QUESTIONS

Q1. (a) Define electric flux. Write its SI unit.

(b) Using Gauss's law, prove that the electric field at a point due to a uniformly charged infinite plane sheet is independent of the distance from it.

(c) How is the field directed if

(i) the sheet is positively charged,

(ii) negatively charged?

CASE STUDY QUESTIONS

Q1. In 1909, Robert Millikan was the first to find the charge of an electron in his now-famous oil-drop experiment. In that experiment, tiny oil drops were sprayed into a uniform electric field between a horizontal pair of oppositely charged plates. The drops were observed with a magnifying eyepiece, and the electric field was adjusted so that the upward force on some negatively charged oil drops was just sufficient to balance the downward force of gravity. That is, when suspended, upward force qE just equaled Mg. Millikan accurately measured the charges on many oil drops and found the values to be whole number multiples of 1.6 x 10-19 C the charge of the electron. For this, he won the Nobel prize.

(i) If a drop of mass 1.08 x 10-14 kg remains stationary in an electric field of 1.68 x 105 N C-1, then the charge of this drop is

(a) 6.40 x 10-19 C (b) 3.2 x 10-19 C

(c) 1.6 X 10-19 C (d) 4.8 x 10-19 C

(ii) Extra electrons on this particular oil drop (given the presently known charge of the electron) are

(a) 4 (b) 3

(c) 5 (d) 8

(iii) A negatively charged oil drop is prevented from falling under gravity by applying a vertical electric field 100 V m-1.If the mass of the drop is 1.6 X 10-3 g, the number of electrons carried by the drop is (g= 10 m s-2)

(a) 1018 (b) 1015

(c) 1012 (d) 109

(iv) The important conclusion given by Millikan's experiment about the charge is

(a) charge is never quantized

(b) charge has no definite value

(c) charge is quantized

(d) charge on oil drop always increases.

NUMERICAL TYPE QUESTIONS

Q1. Two identical particles each having a charge of 10 μC are tied with two strings of equal length 1m at a common point. If both the strings make an angle of 30° with vertical, then determine the mass of each particle.

Q2. Two identical charges are placed at the two corners of an equilateral triangle. The potential energy of the system is U. what will be work done in bringing an identical charge from infinity to the third vertex.

Q3. A sphere of radius 5 cm has electric field 5 × 106 V/m on its surface. What will be the force acting on a charge of 5 × 10–8C placed at distance of 20cm from the center of sphere.

Q4. Two-point charges placed at a certain distance r in air exert a force F on each other. Then the distance R at which these charges will exert the same force in a medium of dielectric constant K.

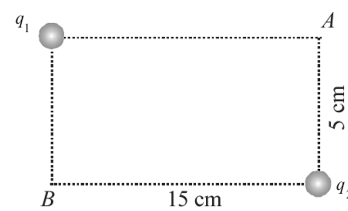
Q5. Two small balls each having the charge +Q are suspended by insulating threads of length L from a hook. This arrangement is taken in space where there is no gravitational effect, then find the angle between the two suspensions and the tension in each thread.

Q6. A total charge Q is broken in two parts Q_1 and Q_2 and they are placed at a distance R from each other. Then when the maximum force of repulsion between them will occur.

Q7. How much kinetic energy will be gained by an α-particle in going from a point at 70V to another point at 50V?

Q8. In a hydrogen atom, the electron revolves around the nucleus in an orbit of radius 0.53×10^{-10}m. Then the electrical potential produced by the nucleus at the position of the electron is

Q9. In the rectangle shown below, the two corners have charges $q_1 = -5\ \mu C$ and $q_2 = +2.0\ \mu C$. Determine the work done by external agent in moving a charge $q = +3.0\ \mu C$ slowly from B to A. (Take $1/4\pi\varepsilon_0 = 10^{10} Nm^2/C^2$)



Q10. The distance between H^+ and Cl^- ions in HCl molecule is 1.28 Å. What will be the potential due to this dipole at a distance of 12 Å on the axis of dipole.

MCQ

S1. (c)2.99×10^{-9} s

$y = \frac{1}{2}at^2 = \frac{1}{2}\frac{eE}{m}t^2, t = \sqrt{\frac{2ym}{e.E}}$

[Putting $y = 4 \times 10^{-2}$ m, $m = 9.1 \times 10^{-31}$ kg,

$e = 1.6 \times 10^{-19}$C, $E = 5 \times 10^4$ N/C]

$t = \sqrt{\frac{2ym}{e.E}} = 3 \times 10^{-9}$ s

S2. (b) Point charges

If the sizes of the charged bodies are very small compared to the distances between them, we consider them as point charges.

S3. (c) $\left(\frac{g}{g+\frac{qE}{m}}\right)^{1/2}$

$T_0 = 2\pi\sqrt{\frac{L}{g}}$

When the plates are charged, the net acceleration is, $g' = g + a$

$g' = g + \frac{qE}{m}$ .... $\left(a = \frac{qE}{m}\right)$

$$\therefore T = 2\pi\sqrt{\frac{L}{g+\frac{qE}{m}}}$$

$$\therefore \frac{T}{T_0} = \left(\frac{g}{g+\frac{qE}{m}}\right)^{1/2}$$

S4. (c) Electric field

The force per unit charge is known as the electric field.

S5. (c) 12×10^{-3} N-m

Charge (q) = 2×10^{-6} C,

Distance (d) = 3cm = 3×10^{-2} m and

Electric field (E) = 2×10^5 N/C.

Torque (τ) = q.d. E=$(2\times10^{-6})\times(3\times10^{-2})\times(2\times10^5)$

= 12×10^{-3} N-m.

S6. (d) Infinite

The dielectric constant of metals is infinite. The dielectric constant of metal is infinite, as the net electric field inside the metal is zero.

S7. (d) 20 N/C

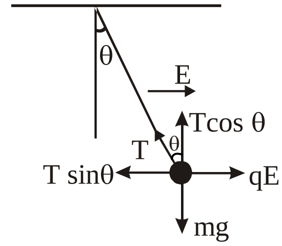
Charge(q) = 0.2 C; Distance (d) = 2 m; Angle θ=60° and Work done (W) = 4J. Work done in moving the charge (W)

= F.d cos θ = qEd cos θ

or, $E = \frac{W}{qd\cos\theta} = \frac{4}{0.2\times2\times\cos 60°} = \frac{4}{0.4\times0.5} = 20$N/C.

S8. (b) Polarity of charge property which differentiates two kinds of charges is called polarity of charge.

S9. (b) 45°



T sin q = qE

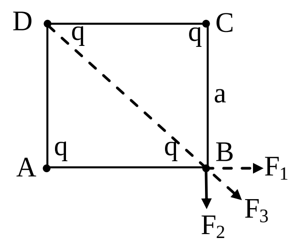
T cos q = mg

$\tan q = \frac{qE}{mg} = \frac{39.2\times10^{-10}\times20\times10^3}{8\times10^{-6}\times9.8}$

tan q = 1

q = 45°

S10. (a) $\frac{1}{2}\frac{kq^2}{a^2}(1 + 2\sqrt{2})$



Force on the charge placed at B, due to charges at A, C, & D are $F_1 = \frac{kq^2}{a^2}$,

$F_2 = \frac{kq^2}{a^2}$ & $F_3 = \frac{kq^2}{(a\sqrt{2})^2} = \frac{kq^2}{2a^2}$ respectively.

[Note BD = $\sqrt{2}$ a]

Resultant of F_1 & F_2,

$F_{12} = \sqrt{F_1^2 + F_2^2 + 2F_1F_2\cos90°} = \sqrt{2}\frac{kq^2}{a^2}$

$F_{12} \parallel F_3$

Q $F = \sqrt{F_{12}^2 + F_3^2 + 2F_{12}.F_3\cos0} = F_{12} + F_3$

$= \frac{\sqrt{2}kq^2}{a^2} + \frac{kq^2}{2a^2}$

$= \frac{1}{2}\frac{kq^2}{a^2}(1 + 2\sqrt{2})$

S11. (c) Electric field

Electric field describes the information on field strength, direction, and also the nature of the charge.

S12. (c) 2.99×10^{-9} s

$y = \frac{1}{2}at^2 = \frac{1}{2}\frac{eE}{m}t^2$ Þ $t = \sqrt{\frac{2ym}{e.E}}$

[Putting $y = 4 \times 10^{-2}$ m, $m = 9.1 \times 10^{-31}$ kg,

$e = 1.6 \times 10^{-19}$C, $E = 5 \times 10^4$ N/C]

$$t = \sqrt{\frac{2ym}{e.E}} = 3 \times 10^{-9} \text{ s}$$

S13. (a) gains protons from silk.

Excess electrons can be transferred from glass to silk when a glass rod is rubbed with silk. Hence, the charge on glass rod becomes positive, and the charge on silk becomes negative.

S14. (b) Er

$$\int_{V_A}^{V_C} dV = -\int_{r_A}^{r_C} \vec{E} \cdot \vec{dr}$$

$$V_C - V_A = -\vec{E}\,(\vec{r}_C - \vec{r}_A)$$

$$= \vec{E} \cdot \vec{r}_{CA}$$

$$= Er_{CA} \cos q$$

$$= Er \cos 0°$$

$$= Er$$

S15. (d) 0.25 e.s.u.

$$V = V_{small} - V_{large} = \frac{kq}{r} - \frac{kq}{R}$$

$$= kq\left[\frac{1}{r} - \frac{1}{R}\right] \qquad ...... (1)$$

q = 3 e.s.u., r = 4 cm, R = 6 cm and

In C.G.S. k = 1 dyne cm^2/stat. coulomb^2

$$\text{From (1) } V = 3\left[\frac{1}{4} - \frac{1}{6}\right] = 0.25 \text{ e.s.u.}$$

S16. (d) 1.6×10^{-15} Newton

$E = 10^4$ Newton per Coulomb and $q = 1.6 \times 10^{-19}$ C

F = q E

F = (1.6×10^{-19})x104

F = 1.6×10^{-15} Newton

S17. (d) Electrostatic field lines form closed loops

The space around an electric charge in which other charged particles can feel the electrostatic force is referred to as the electric field by that electric charge. Electric field lines are imaginary lines that are used to illustrate the electric field.

The direction of the electric field at a location on the electric field line is given by the tangent line. Field lines begin with a positive charge and end with a negative charge. They begin and stop at right angles to the charge's surface. There are no loops in electric field lines. Where the number of field lines is greatest, the size of the electric field is greatest.

S18. **(a)** Charge of the particle

In an electric field, the magnitude of the electric force experienced by a charged particle is given by,

F=Eq°

The magnitude of the electric force experienced by a charged particle in an electric field is dependent on the magnitude of the charge on the **particle**, as shown by the above equation.

S19. (c) Inside the sphere

The electric field within the hollow sphere is zero. They cancel each other out since E is a vector quantity. There is no electric field in the middle. The external field is canceled by the inside field. The electrical charge is always spread evenly throughout the uniformly formed wire.

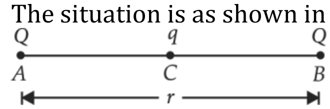
S20. (b) Electric field

The force experienced by a unit charge deposited at any point is specified as the electric field intensity (E). The intensity of an electric field at a particular point is given by:

E=F/q

As a result, the force acting per unit positive test charge at a given place is a measure of the electric field's intensity.

S21. (a) The situation is as shown in the figure.



Let two equal charges Q each placed at points A and B at a distance r apart. C is the centre of AB where charge q is placed.

For equilibrium, net force on charge $Q = 0$

$$\therefore \qquad \frac{1}{4\pi\varepsilon_0}\frac{QQ}{r^2} + \frac{1}{4\pi\varepsilon_0}\frac{Qq}{(r/2)^2} = 0$$

$$\frac{1}{4\pi\varepsilon_0}\frac{Q^2}{r^2} = -\frac{1}{4\pi\varepsilon_0}\frac{4Qq}{r^2} \text{ or } Q = -4q \text{ or } q = -\frac{Q}{4}$$

S22. (a) giving excess of electrons to it excess of electron gives the negative charge on body.

S23. (a) Field line are always normal to conducting surface and they do not from closed loop. Field may have break, the do not exist inside the conductor.

S24. (a) any closed surface Gauss's law states that flow through any closed surface is a measure of the total charge inside. Gauss law is valid for closed surfaces. it is valid only for the symmetric body charge distribution such as spherical, cylindrical, plane symmetry. It is also a valid other medium such as dielectric medium.

S25. (a) decreases by K times $F' = \frac{1q_1q_2}{4\pi\varepsilon_0 r^2} = \frac{F}{K}$

If F is the force in air, then F' is less than F since K>1.

ASSERTION AND REASONING

S1. (a) Protons and electrons are the only basic charges in the universe. All the observable charges have to be integral multiple of e. Thus, if a body contains n electrons and m protons. The total number of charge in the body is m.e + n(-e) = (m-n)e. Since n and m are integers, their difference is also an integer. Thus, the charge on a body is always an integral multiple of e and can be increased or decreased in terms of e.

S2. **(b)** Force on any charge due to a number of other charges is the vector sum of all the forces on that charge due to the other charges, taken one at a time the individual force is unaffected due to the presence of other charges. This is known as the principle of superposition of charges.

S3. **(d)** Whenever we rub a glass rod with silk cloth, electrons from the glass rod and transferred to the silk cloth. Thus, the rod gets positively charged and the cloth gets negatively charged.

S4. **(d)** Gravitational force is the dominating force in the nature and not coulomb's force. Gravitational force is the weakest force. Also, coulomb's force is very strong force than gravitational force.

S5. **(d)** The rate of decrease of electric field is different in the two cases in case of point charge is it decreases as $1/r^2$ but in the case of electric dipole, it decreases more rapidly as $1/r^3$.

VERY SHORT ANSWER QUESTIONS

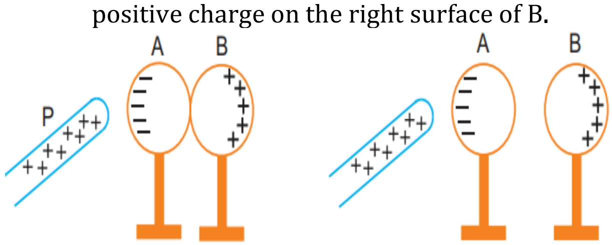
S1. Net electric flux is zero, Because of the independent to the shape and size and also because of the charge of the electric dipole is zero.

S2. Electric field lines start from positive charge and terminate at negative charge. If there is a single positive charge, the field lines start from the charge and terminate at infinity. So, the electric field lines do not form closed loops

S3. Final charge on balls A and B = $3Q - \frac{Q}{2} = Q$

The nature of the coulomb force between them is repulsive.

S4. Let us consider sphere A will be negatively charged. And the Sphere B will be positively charged. If positively charged rod P is brought near metallic sphere A due to induction negative charge starts building up at the left surface of A and positive charge on the right surface of B.

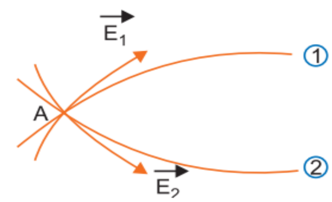


Let us consider one more condition, the two spheres are separated from each other, the two spheres are found to be oppositely charged. If rod P is removed, the charges on spheres rearrange themselves and get uniformly distributed over them.

S5. The electric fields bind the atoms to neutral entity. Fields are caused by excess charges. There can be no excess charge on the inner surface of an isolated conductor. So, the electrostatic field inside a conductor will becomes zero.

SHORT ANSWER QUESTIONS

S1.



(a) An electrostatic field line is the path of movement of a positive test charge ($q_0 \rightarrow 0$) A moving charge experiences a continuous force in an electrostatic field, so an electrostatic field line is always a continuous curve.

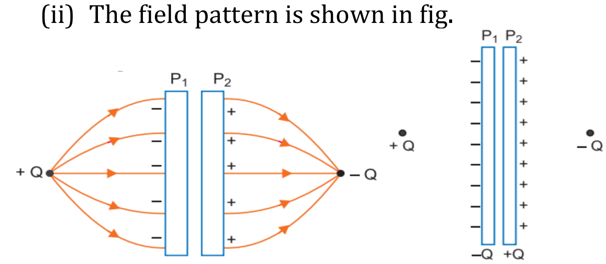
(b) If two electric lines of force can never cross each other because if they cross, there will be two directions of electric field at the point of intersection (say A); which is totally impossible.

S2. **(a)** The total number of electric field lines crossing a surface normally is known as the electric flux. The SI unit of electric flux is $Nm^2\,C^{-1}$ or Vm.

(b) Total electric flux through the surface= q / ε_0. As charge remains unchanged when size of balloon increases, electric flux through the surface remains unchanged.

S1. (i) Charges induced on outer surfaces of P1 and P2 are – Q and + Q respectively. When plates are released, they will tend to move away from one another; plate P1 moving towards +Q and P2 towards –Q due to attraction.

(ii) The field pattern is shown in fig.



S4. Ans. Electric field due to a uniformly charged plane sheet.

$E = \sigma/2\varepsilon_0$

which is independent of distance. So, it represents a straight line parallel to distance axis.

S5. **(a)** Total number of electric field lines crossing a surface normally is called electric flux. Its SI unit is $Nm^2\,C^{-1}$ or Vm

(b) According to Gauss theorem, the electric flux through a closed surface depends on the net charge enclosed by the surface and does not upon the shape or size of the surface. For any closed arbitrary shape of the surface enclosing a charge the outward flux is the same as that due to a spherical Gaussian surface enclosing the same charge.

The reason behind this is, it happens due to the fact that (i) electric field is radial and (ii) the electric field E $\propto \frac{1}{R^2}$

Thus, the electric field at each point inside a charged thin spherical shell is zero.

CASE STUDY QUESTIONS

S1. (i). (c), (ii). (a), (iii). (c), (iv). (c)

S2. (a) (i). (b), (ii) . (b), (iii).

S3. (i). a, (ii) (C), (iii) (a), (iv). (b)

S4. (i). (b), (ii). (c), (iii).(b)

NUMERICAL TYPE QUESTIONS

S1. Energy density,

$U = \frac{1}{2}\varepsilon_0 E^2$

But we know that,

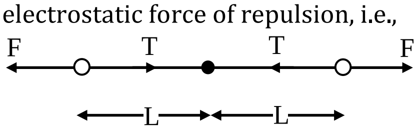
$E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{A\varepsilon_0}$

Therefore,

$U = \frac{1}{2}\frac{\varepsilon_0 Q^2}{A^2\varepsilon_0^2}$

$\Rightarrow U = \frac{Q^2}{2A^2\varepsilon_0} \Rightarrow U \propto \frac{1}{A^2} \Rightarrow U_A > U_B$

S2. Where there is no gravitational force, then in this case only electrostatic force of repulsion is acting which will take the two balls as far as possible. The angle between the two strings will be 180° . The tension in the string will be equal to the electrostatic force of repulsion, i.e.,



(Electrostatic force acting between two charged balls)

F = $\frac{kQ^2}{(2L)^2} = \frac{kQ^2}{4L^2}$

$\because$ T = F = $\frac{kQ^2}{4L^2}$ where, k=$\frac{1}{4\pi\varepsilon_0}$

S3. Since the kinetic energy imparted to a system because of accelerated voltage V.

KE = qV

Kinetic energy= $\frac{1}{2}$ mv^2

From above two equation we can write,

$\frac{K_A}{K_B} = \frac{qV}{4qV} = \frac{1/2mV_A^2}{1/2mV_B^2}$

$\frac{V_A^2}{V_B^2} = \frac{1}{4} = \frac{1}{2}$

S4. $q = 20\mu C = 2.0 \times 10^{-6} C$

Here, net electrical flux through the cubical surface is,

$\varphi_E = \frac{q}{\varepsilon_0} = \frac{2.0\times10^{-6}}{8.85\times10^{-12}} = 2.26 \times 10^5 Nm^2C^{-1}$

S5. (a) The electric flux through a surface is depends only on the charge enclosed by the surface. If the radius of the spherical surface is doubled, the charge enclosed remains the same, so the electric flux passing through the surface will remain unchanged.

(b) If q is the point charge, then by Gauss theorem, the electric flux $\varphi_E = \frac{q}{\varepsilon_0}$

$\therefore$ q = $\varphi\varepsilon_0$

$\varphi_E = 8.85 \times 10^{-12} \times (-1.0 \times 10^3)$

$\varphi_E = -8.85 \times 10^{-9} C$

S6. (a) Radius of sphere, r = $\frac{\text{Diameter}}{2} = \frac{2.4}{2} m = 1.2\ m$

Surface charge density, σ=$80.0\mu Cm^{-2} = 80.0 \times 10^{-6} C/m^2$

Charge on sphere Q = $\sigma \times 4\pi r^2$

$= 80.0 \times 10^{-6} \times 4 \times 3.14 \times (1.2)^2$

$=1.447 \times 10^{-3} C$

(c) Total electric flux leaving the surface of the sphere

$\varphi_E = \frac{q}{\varepsilon_0} = \frac{1.45\times10^{-3}}{8.85\times10^{-12}}$

$= 1.63 \times 10^8 Nm^2C^{-1}$

Q7. A piece of metal has a charge +1 × 10^{-7}C the body lost electrons and hence achieved a positive charge.

Now the charge of each electron is -1.6 × 10^{-19}C

Now, the Number of electrons removed-

Number of electrons =$\frac{1\times10^{-7}}{1.6\times10^{-19}}$

$\Rightarrow$ number of electrons= 0.625 ×10^{19-7}

$\Rightarrow$ number of electrons= 0.625 ×10^{12}

$\Rightarrow$ number of electrons = 6.25 ×10^{11}

S8. Electric field intensity at the centre of the disc.

$E = \frac{\sigma}{2\epsilon_0}$ (given)

Electric field along the axis at any distance x from the centre of the disc.

E' = $\frac{\sigma}{2\epsilon_0}\left(1 - \frac{x}{\sqrt{x^2+R^2}}\right)$

From question, x = R (radius of disc)

$\therefore$ E' = $\frac{\sigma}{2\epsilon_0}\left(1 - \frac{R}{\sqrt{R^2+R^2}}\right)$

$= \frac{\sigma}{2\epsilon_0}\left(\frac{\sqrt{2}R-R}{\sqrt{2}\,R}\right)$

$= \frac{4}{14}\ E$

$\therefore$ % Reduction in the value of electric field

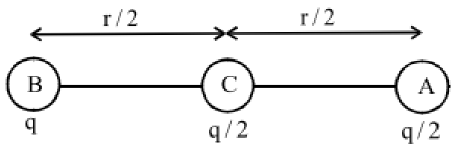
$= \frac{\left(E-\frac{4}{14}E\right)\times100}{E} = \frac{1000}{14}\% \simeq 70.7\%$

S9. $\phi = \vec{E}.\vec{A} = 4\hat{\imath}.(2\hat{\imath} + 3\hat{\jmath}) = 8$V-m

S10. Initial force between the two spheres carrying charge (say q) is

$F = \frac{1}{4\pi\epsilon_0}\frac{q^2}{r^2}$ (r is the distance between them)

Further when an uncharged sphere is kept in touch with the sphere of charge q, the net charge on both become $\frac{q+0}{2} = \frac{q}{2}$. Force on the 3rd charge, when placed in center of the 1st two



$F_3 = \frac{1}{4\pi\epsilon_0}\frac{q\left(\frac{q}{2}\right)}{\left(\frac{r}{2}\right)^2} - \frac{1}{4\pi\epsilon_0}\frac{\left(\frac{q}{2}\right)^2}{\left(\frac{r}{2}\right)^2}$

$= \frac{1}{4\pi\epsilon_0}\frac{q^2}{r^2}[2-1] = F$

S11. Mass of water, = 250g

The Molecular mass of water = 18g

Number of molecules in 18g of water = 6.02×10^2

Number of molecules in one cup of water = $\frac{250}{18} \times 6.02 \times 10^{23}$

Each molecule of water contains two hydrogen atoms and one oxygen atom,

i.e., 10 electrons and 10 protons.

Total negative charge present in one cup of water

$= \frac{250}{18} \times 6.02 \times 10^{23} \times 10 \times 1.6 \times 10^{19} C$

Total negative charge present in one cup of water

$= 1.34 \times 10^7$

S12. E $= -dv/dx$

V = $(5x^2 - 10x - 9)$ v

dV/dx = 10 x -10

$E = -(10x - 10)$

for x=1 the value of E= -(10-10) = 0 V/m

HOMEWORK EXERCISE SOLUTIONS

MCQ

S1. **(b)** Net electrostatic energy

$U = \frac{kQq}{a} + \frac{kq^2}{a} + \frac{kQq}{a\sqrt{2}} = 0$

$\Rightarrow \frac{kq}{a}\left(Q + q + \frac{Q}{\sqrt{2}}\right) = 0 \Rightarrow Q = -\frac{2q}{2+\sqrt{2}}$

S2. **(c)** $\Rightarrow \frac{kq}{l}(Q + q + Q) = 0 \Rightarrow Q = -\frac{q}{2}$ net potential energy

$U_{net} = 3 \times \frac{1}{4\pi\varepsilon_0} \cdot \frac{q^2}{l}$

S3. **(c)** $U_{System} = \frac{1}{4\pi\varepsilon_0}\frac{(q)(-2q)}{a} + \frac{1}{4\pi\varepsilon_0}\frac{(-2q)(q)}{a} + \frac{1}{4\pi\varepsilon_0}\frac{(q)(q)}{2a}$

$U_{System} = -\frac{7q^2}{4\pi\varepsilon_0 a}$

S4. **(b)** perpendicular to surface Because there are no parallel components of field lines on the surface of a charged conductor, the electric field at any location on the surface is perpendicular to the surface. Because all of the charges are collected on the conductor's surface, this is the case.

S5. **(d)** Downward force of magnitude eE Given that the proton charge q = e and the electric field E are both equal (downward)
As a result, force F = qE.
F = eE
Because force is always in the direction of the electric field, it will be downward.

S6. **(c)** Inside the sphere
The electric field within the hollow sphere is zero. They cancel each other out since E is a vector quantity. There is no electric field in the middle. The external field is canceled by the inside field. The electrical charge is always spread evenly throughout the uniformly formed wire.

S7. **(b)** No electric field lines of force may begin or end on the same conductor
An equipotential line is a line that connects locations with the same potential. Electric field lines are perpendicular to equipotential lines. The direction of the electric field at each location on the electric field line is represented by the tangent to that point.

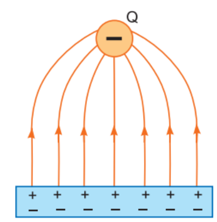
S8. **(c)** The electrical field at that point A charged particle's environment in which it exerts an electrostatic force on another item. The force of electrostatic attraction or repulsion is applied to a test charge when it enters the electric field of any charged particle.

S9. **(c)** Vm^{-1} The electric field is defined as the force produced by charge or potential multiplied by distance. The volt is the SI unit of electric potential, whereas the meter is the SI unit of distance. Volt/meter, or V m^{-1}, is the unit of potential by distance.

S10. (b) 10 N/C towards the south
Given q_o = -6C, and F = 60 N towards north
We know that the electric field intensity is given as,
$E=F/q_o$
E=60/6
⇒ E = 10 N/C
The electric field exerts a pull on the negative charge in the opposite direction. As a result, the electric field is directed southward.

VERY SHORT ANSWER QUESTIONS

S1.



As –Q charge is kept near an uncharged conducting plate, positive charge is induced on the plate due to electrostatic induction. The field lines will be perpendicular to the metal surface.

S2. Electric field lines start from positive charge and terminate at negative charge. If there is a single positive charge, the field lines start from the charge and terminate at infinity. So, the electric field lines do not form closed loops.

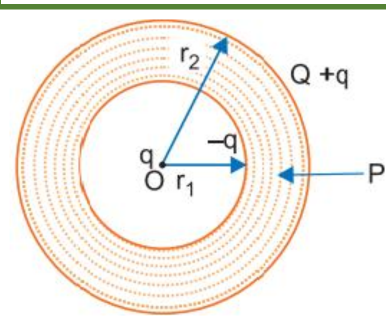
S3. The electric fields bind the atoms to neutral entity. Fields are caused by excess charges. There can be no excess charge on the inner surface of an isolated conductor. So, the electrostatic field inside a conductor is zero.

S4. Zero because the net charge of an electric dipole (+ q and – q) is zero.

S5. The electric lines of force give the direction of the electric field. In case, two lines of force intersect, there will be two directions of the electric field at the point of intersection, which is not possible.

SHORT ANSWER QUESTIONS

S1.



(a) Charge Q resides on outer surface of spherical conducting shell. Due to charge q placed at centre, charge induced on inner surface is –q and on outer surface it is +q. So, total charge on inner surface –q and on outer surface it is Q + q.

(i) Surface charge density on inner surface $= -\frac{q}{4\pi r_1^2}$

(ii) Surface charge density on outer surface $= \frac{Q+q}{4\pi r_2^2}$

For external points, whole charge acts at centre, so electric field at distance x>r2,

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

S2. If the electric field lines were not normal to the equipotential surface, it would have a non-zero component along the surface. To move a unit test charge against the direction of the component of the field, work would have to be done which means this surface cannot be equipotential surface. Hence, electric field lines are perpendicular at a point on an equipotential surface of a conductor.

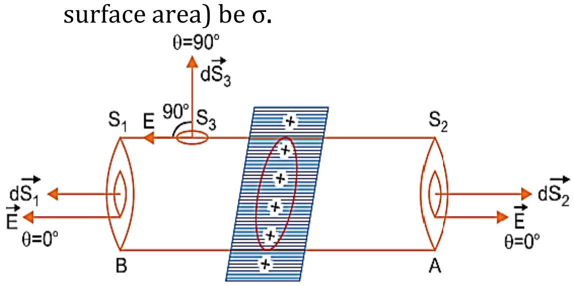
LONG ANSWER QUESTIONS

S1. (a) Electric flux: It is defined as the total number of electric field lines passing through an area normal to its surface. Also,

$\varphi = \oint \vec{E}.\vec{dS}$

The SI unit is Nm^2 /C or volt-metre.

(b) Let electric charge be uniformly distributed over the surface of a thin, non-conducting infinite sheet. Let the surface charge density (i.e., charge per unit surface area) be σ.



Sheet

We need to calculate the electric field strength at any point distant r from the sheet of charge. To calculate the electric field strength near the sheet, we now consider a cylindrical Gaussian surface bounded by two plane faces A and B lying on the opposite sides and parallel to the charged sheet and the cylindrical surface perpendicular to the sheet (fig). By symmetry the electric field strength at every point on the flat surface is the same and its direction is normal outwards at the points on the two plane surfaces and parallel to the curved surface. Total electric flux or

$\oint_S \vec{\mathbf{E}} \cdot d\vec{\boldsymbol{S}} = \int_{S_1} \vec{\mathbf{E}} \cdot d\vec{\boldsymbol{S}}_1 + \int_{S_2} \vec{\mathbf{E}} \cdot d\vec{\boldsymbol{S}}_2 + \int_{S_3} \vec{\mathbf{E}} \cdot d\vec{\boldsymbol{S}}_3$

$\oint_S \vec{\mathbf{E}} \cdot d\vec{\boldsymbol{S}} = \int_{S_1} EdS_1 \cos 0^\circ + \int_{S_2} EdS_2 \cos 0^\circ + \int_{S_3} EdS_3 \cos 900$

$= E\int dS_1 + E\int dS_2 = Ea + Ea = 2Ea$

∴ Total electric flux = 2Ea

As σ is charge per unit area of sheet and a is the intersecting area, the charge enclosed by Gaussian surface = σa

According to Gauss's theorem,

Total electric flux=$1/\varepsilon_0$ × (total charge enclosed by the surface)

$2Ea = \frac{1}{\varepsilon_0(\sigma a)}$

$E = \frac{\sigma}{2\varepsilon_0}$

Thus, electric field strength due to an infinite flat sheet of charge is independent of the distance of the point.

(c) (i) If σ is positive, $\vec{E}$ points normally outwards/away from the sheet.

(ii) If σ is negative, $\vec{E}$ points normally inwards/towards the sheet.

CASE STUDY QUESTIONS

S1. (i) (a) 6.40 x 10^{-19} C

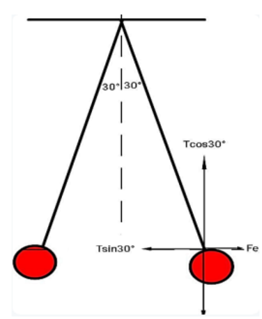
(ii) (a) 4

(iii) (c) 10^{12}

(iv) (c) charge is quantized

NUMERICAL TYPE QUESTIONS

S1.



free body diagram of particles is shown clearly.

at equilibrium,

upward force = downward force

Tcos30° = mg ....(1)

backward force = forward force

Tsin30° = Fe = kq^2/r^2 ......(2)

where r = 2lsin30° , where l = length of string.

from equation (1) and (2),

tan30° = kq^2/r^2mg

or, 1/√3 = $kq^2/(2l\sin30°)^2mg$

or, m = √3$kq^2/4l^2\sin^2 30g$

here, k = 9 × 10^9 Nm^2/C^2 , q = 10^{-5} , l = 1m and g = $10m/s^2$

so, m = √3 × 9 × 10^9 × $(10^{-5})^2$/{4 × 1 × $(1/2)^2$ × 10}

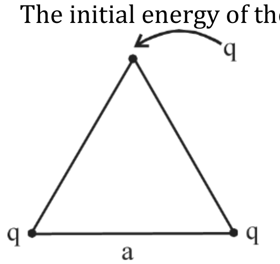
= 9√3 × 10^{-1}/{10}

= 9√3/100

= 15.588/100

= 0.15588 kg≈ 0.15 kg

S2. The initial energy of the system



$U_i = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{a} = U$

The final energy of the system

$U_f = \frac{1}{4\pi\varepsilon_0}\left[\frac{q^2}{a} + \frac{q^2}{a} + \frac{q^2}{a}\right] = 3U$

Thus, work done, $W = U_f - U_i = 3U - U = 2U$

S3. At surface, $E_S = \frac{kq}{R^2} \Rightarrow kq = E_S R^2$

At distance r =20 cm from the center $E= \frac{kq}{r^2}$

So, force on charge Q = 5 × 10^{-8} C

F = QE = $\frac{QE_sR^2}{r^2}$

Putting Q = 5 × 10^{-8} C, E_S = 5 × 10^6 V/m,

R = 0.05 m, r = 0.20 cm

F = 1.5 × 10^{-2} N

S4. the two-point charges = q_1 and q_2 distance between them = r

Force exerted on each other = F

the dielectric constant of the medium = K

the distance at which both charges will exert the same force, R.

To calculate D, the formula used:

$F = \frac{q_1q_2}{4\pi\epsilon_0 r^2}$

ϵ_0 is the vaccum permittivity

Applying the above formula, when the distance between the charges is r:

$F_1 = \frac{q_1q_2}{4\pi\epsilon_0 r^2} \Rightarrow 1$

When the dielectric constant of the medium is K and the distance between the two charges is R, then the force exerted is:

$F_2 = \frac{q_1q_2}{k\,4\pi\epsilon_0 R^2} \Rightarrow 2$

But, $F_1 = F_2 = F$

Put, $F_1 = \frac{q_1q_2}{4\pi\epsilon_0 r^2}$

$\therefore \frac{q_1q_2}{4\pi\epsilon_0 r^2} = \frac{q_1q_2}{k(4\pi\epsilon_0 R^2)}$

$\Rightarrow \frac{1}{r^2} = \frac{1}{R^2\,k}$

Taking square-root on both the side:

$\sqrt{\frac{1}{r^2}} = \sqrt{\frac{1}{R^2\,k}}$

$$\frac{1}{r} = \frac{1}{R\sqrt{k}}$$

Taking reciprocal on both the side

r = R √K

r / √K = R

$R = \frac{r}{\sqrt{k}}$

Hence the distance at which both charges will exert the same force is $R = \frac{r}{\sqrt{k}}$

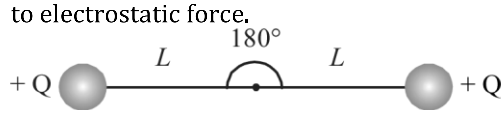
S5. Charge= +Q

Length =L

g=0

this means there will be no force downwards.

So, the charges will go up to maximum reach due to electrostatic force.



The angle between them will be $\theta = 180°$

Now, tension will be force between two charges.

$T=F = \frac{1}{4\pi\epsilon_0}.\frac{Q^2}{(2L)^2}$

S6. $Q_1 + Q_2 = Q$ ...(i)

and $F = k\frac{Q_1Q_2}{r^2}$ ...(ii)

From (i) and (ii)

$F = \frac{kQ_1(Q-Q_1)}{r^2}$

Differentiating w.r.t Q 1 and equating to 0 for maximum force, we get

For F to be maximum

$\frac{dF}{dQ_1} = 0 \Rightarrow Q_1 = Q_2 = \frac{Q}{2}$

S7. $KE = q(V_1 - V_2) = 2 \times (70 - 50)\Omega = 40\ eV$

S8. $V = k \times \frac{Q}{r} = 9 \times 10^9 \times \frac{(+1.6\times10^{-19})}{0.53\times10^{-10}} = 27.2V$

S9. Work done $W = q^{-6}(V_A - V_B)$; where $q = 3 \times 10^{-6}$ coulomb were

$V_A = 10^{10}\left[\frac{(-5\times10^{-6})}{15\times10^{-2}} + \frac{2\times10^{-6}}{5\times10^{-2}}\right] = \frac{1}{15} \times 10^6\ volt$

and V_B $= 10^{10}\left[\frac{(2\times10^{-6})}{15\times10^{-2}} - \frac{5\times10^{-6}}{5\times10^{-2}}\right]$

$= -\frac{13}{15} \times 10^6\ volt$

$\therefore W$ $= 3 \times 10^{-6}\left[\frac{1}{15} \times 10^6 - \left(\frac{13}{15} \times 10^6\right)\right]$ = 2.8 J

S10. $V = 9 \times 10^9.\frac{p}{r^2}$

$= 9 \times 10^9 \times \frac{(1.6\times10^{-19})\times1.28\times10^{-10}}{(12\times10^{-10})^2} = 0.13V$