PART – I : ELECTROSTATICS

CHAPTER 1 ELECTRIC CHARGES AND FIELDS

Syllabus

- *Electric Charges; Conservation of charge, Coulomb's law-force between two-point charges, forces between multiple charges; superposition principle and continuous charge distribution. Electric field, electric field due to a point charge, electric field lines, electric dipole, electric field due to a dipole, torque on a dipole in uniform electric field. Electric flux, statement of Gauss's theorem and its applications to find field due to infinitely long straight wire, uniformly charged infinite plane sheet.*

Revision Notes

Electric Field and Dipole

Electric Charge

- Electric charge is the property of a matter due to which, it experiences a force when placed in an electromagnetic field.
- Point charge is an accumulation of the electric charges at a point, without spatial extent.
- Electrons are the smallest and lightest fundamental particles in an atom having negative charge as these are surrounded by invisible force known as electrostatic field.
- Protons are comparatively larger and heavier than electrons with positive electrical charge which is similar in strength as electrostatic field in an electron with opposite polarity.
- Two electrons or two protons will tend to repel each other as they carry like charges, negative and positive respectively.
- The electron and proton will get attracted towards each other due to their unlike charges.
- The charge present on the electron is equal and opposite to charge on the proton.

$$\text{Charge on a proton} = +1.6 \times 10^{-19}\text{ C}$$
$$\text{and charge on an electron} = -1.6 \times 10^{-19}\text{ C}$$

Electrostatic Charge

- Electrostatic charge means the charge is at rest.
- Electrostatic charge is a fundamental physical quantity like length, mass and time.
- Charge on a body is expressed as $q = \pm ne$
- The magnitude of charge is independent of the speed of the particle.
- Based on the flow of charge across them, materials are classified as:
    - Conductors - Allow electric charge to flow freely, *e.g.* metals

Electric Charges & Fields

Electric charges
- 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 = 1.602×10^{-19}C

Quantization of charge
All charges must be a multiple of charge (e)
$Q = ne$
Where n is an integer

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

Coulomb's Law
In 1985, Charles Augustin de Coulomb gave Coulomb's law

- Force between two charged particles

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

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

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

- Force between multiple charges

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

where is the unit vector along charge particle under consideration
$\hat{r}_{li}$ = distance between Ist and i^{th} particle

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

Electric flux
$\Delta\phi = \overline{E}.\Delta\overline{S}$, $\Delta\overline{S}$ = area vector
$\overline{E}$ = electric field
$\phi = \int \overline{E}.\overline{ds}$

Gauss's Theorem
$\oint \overline{E}.\overline{ds} = q_{in}/\varepsilon_0 = \phi$
where, q_{in} = net charge enclosed
ϕ = flux through a closed surface

Applications of Gauss's Law
- Electric Field due to linear charge distribution
  $E = \lambda/2\pi\,\varepsilon_0 r$,
  λ = linear charge density
- Electric Field due to a plane sheet of charge
  $E = \sigma/2\varepsilon_0$,
  σ = charge per unit area
- Electric Field due to a charged conducting plate
  $E = \sigma/\varepsilon_0$,
  σ = charge per unit area
- Electric Field inside a conductor = 0

Electric field due to uniformly charged spherical shell at :
- Outside point,
  $E = Q/4\pi\varepsilon_0 r^2$
- Internal point,
  E = 0
- The surface,
  $E = Q/4\pi\varepsilon_0 R^2$

Electric Field

Electric field lines
- Always normal to conducting surface
- Lines originating from +ve charge
- Terminating at –ve charge
- Never intersect each other
- Do not form closed loop
- Are imaginary lines.

Electric field due to point charge
$\vec{E} = \frac{\vec{F}}{q} = k\,\frac{Q}{r^2}$ (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
  $\vec{E} = k\int\frac{dQ}{r^3}\vec{r}$
  $|\vec{E}| = k\int\frac{dQ}{r^2}$

Electric Dipole moment, $\vec{p} = q\vec{d}$
- Electric field due to dipole at axial position,
  $\vec{E} = \frac{1}{4\pi\,\varepsilon_0}\left(\frac{2p}{r^3}\right)\hat{r}$
- Electric field due to dipole at an equatorial position,
  $|E| = \frac{1}{4\pi\,\varepsilon_0}\left(\frac{p}{r^3}\right)$
- Torque on an electric dipole placed in an electric field $(\vec{E})$
  $\vec{\tau} = \overline{p}\times\overline{E} = p\,E\sin\theta$

Trace the Mind Map
- First Level
- Second Level
- Third Level

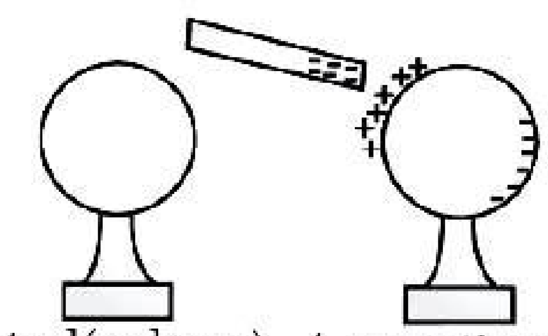
- Semi-conductors - Behave as the conductor or insulator depending on the number of free electrons and holes availability. e.g. silicon
- Insulators - Do not allow electric charge to flow, *e.g.* rubber, wood, plastic, etc.

➢ **Net charge on a body is given by:**
- Charging by friction - Charging insulators
- Charging by conduction - Charging metals and other conductors
- Charging by induction - Wireless charging

Charging by Rubbing

➢ On rubbing a glass rod and silk cloth piece together, glass rod gets positively charged whereas silk cloth gets negatively charged.

➢ If a plastic rod is rubbed with wool, it becomes negatively charged.



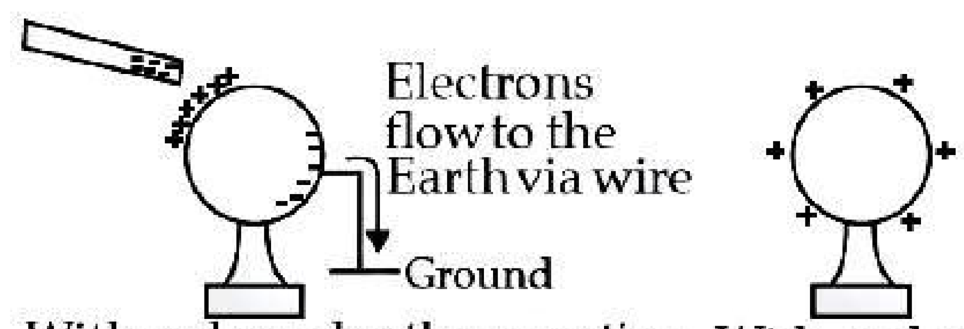
Neutral(sphere) A negative rod near by separates +ve and –ve charges

Charging by Induction

➢ Charging by induction means charging without contact.

➢ If a negatively charged rod is brought near neutral metal with insulator mounting, it repels free electrons and attracts positive charges on metal.

➢ If far end is connected to Earth by a wire, electrons will flow towards ground while positive charges are kept captive by the rod.



With rod nearby the negative end may be discharged. With rod away, the positive charges distribute evenly

➢ When the rod is removed, the captive positive charge is distributed evenly.

Properties of Electric Charge

Addition of charges

➢ If a system contains three point charges q_1, q_2 and q_3, then the total charge of the system will be the algebraic addition of q_1, q_2 and q_3, *i.e.*, charges will add up.

$$q = q_1 + q_2 + q_3$$

Conservation of charges

➢ Electric charge is always conserved. It is the sum of positive and negative charges present in an isolated system, which remains constant.

➢ Charge can neither be created nor destroyed in the process, but only exists in positive-negative pairs.

Quantization of charges

➢ Electric charge is always quantized *i.e.*, electric charge is always an integral multiple of charge 'e'.

➢ Net charge q_{net} of an object having N_e electrons, N_p protons and N_n neutrons is:

$q_{net} = -eN_e + eN_p + 0N_n = e(N_p - N_e) = \pm ne$

➢ Neutron (n): $m = 1.675 \times 10^{-27}$ kg; $q = 0$

➢ Proton (p): $m = 1.673 \times 10^{-27}$ kg; $q = +1.6 \times 10^{-19}$ C

➢ Electron (e): $m = 9.11 \times 10^{-31}$ kg; $q = -1.6 \times 10^{-19}$ C

Coulomb's Law

➢ The force of attraction or repulsion between two point charges q_1 and q_2 separated by a distance r is directly proportional to product of magnitude of charges and inversely proportional to square of distance between charges, written as:

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

where,

F = Force of attraction/repulsion between charges q_1 and q_2.

q_1, q_2= Magnitudes of charge 1 and charge 2 respectively

r = Distance between charges q_1, q_2

k = Constant whose value depends on medium where charges are kept. $k = \dfrac{1}{4\pi\varepsilon}$

As $\varepsilon = K'\varepsilon_0$, $k = \dfrac{1}{4\pi K'\varepsilon_0}$

ε_0 = Permittivity of vacuum = 8.854×10^{-12} F/m

K' = Relative permittivity of medium or dielectric constant.

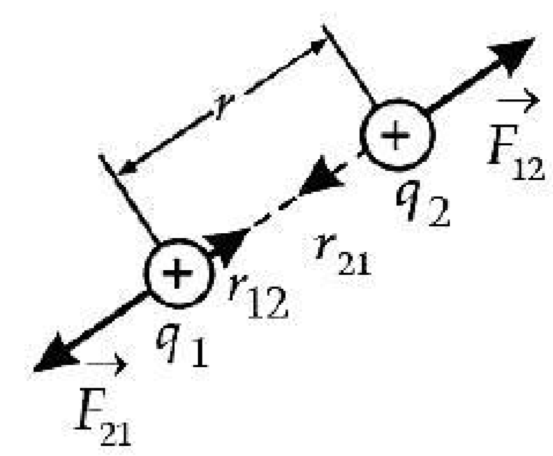
- For vacuum, relative permittivity, $K' = 1$,
- As $\varepsilon = K' \varepsilon_0$, therefore force of attraction/repulsion between two electric charges q_1, q_2 placed in vacuum and medium will be:

$$F = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r^2} \text{ (vacuum) and } F = \frac{1}{4\pi\varepsilon_0\varepsilon_r} \cdot \frac{q_1 q_2}{r^2} \text{ (medium)}$$

- The unit coulomb (C) is derived from the SI unit ampere (A) of the electric current.
- Current is the rate $\frac{dq}{dt}$ at which charge moves past a point or through a region, $i = \frac{dq}{dt}$, hence 1 C=(1 A) × (1 s).
- The vector form of Coulomb force with $\hat{r}_{12}$ = unit vector from q_1 to q_2 is given as:

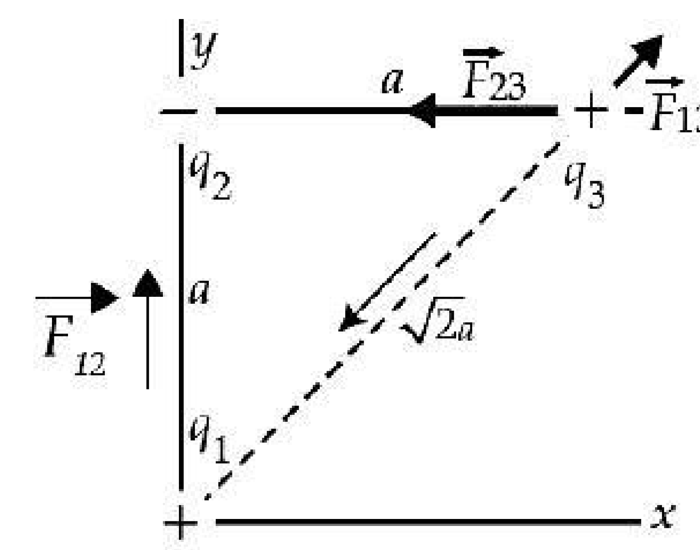
$$\vec{F}_{12} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r^2} \hat{r}_{12} \text{ and } \vec{F}_{21} = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r^2} \hat{r}_{21}$$

$$\Rightarrow \quad \vec{F}_{21} = -\vec{F}_{12}$$



Principle of Superposition

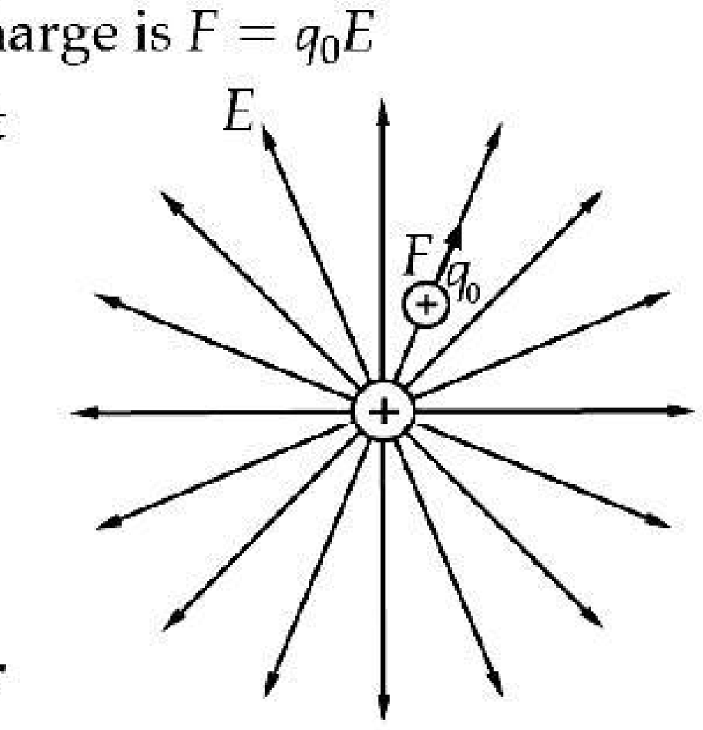
- The force on any charge due to other charges at rest is the vector sum of all the forces on that charge due to the other charges, taken one at a time.
- The individual forces are unaffected due to presence of other charges.
- Force exerted by q_1 on $q_3 = \vec{F}_{13}$
- Force exerted by q_2 on $q_3 = \vec{F}_{23}$
- Net force exerted on q_3 is vector sum of $\vec{F}_{13}$ and $\vec{F}_{23}$



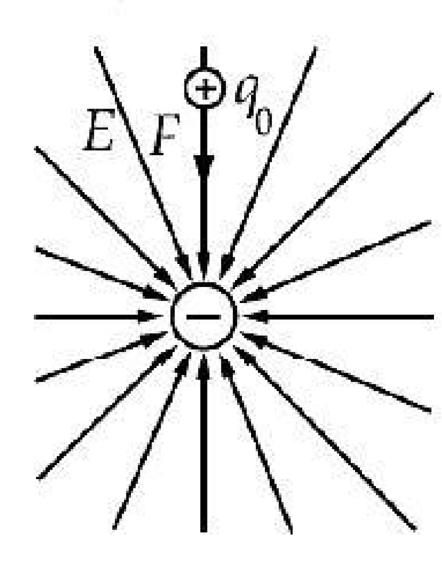
Electric field

- The space around a charge up to which its electric force can be experienced is called electric field.
- If a test charge q_0 is placed at a point where electric field is E, then force on the test charge is $F = q_0 E$
- The electric field strength due to a point source charge 'q' at an observation point 'A' at a distance 'r' from the source charge is given by:

$$\vec{E} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r^3} \vec{r} \text{ or } E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r^2}$$

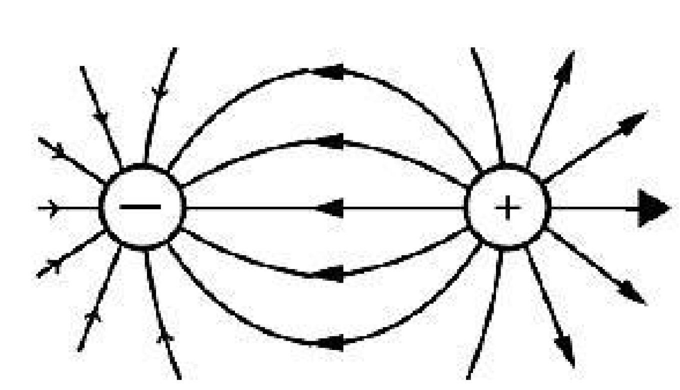


- The unit of electric field is N/C.
- Electric field inside the cavity of a charged conductor is zero.
- If a charged/uncharged conductor is placed in an external field, the field in conductor is zero.
- In case of charged conductor, electric field is independent of the shape of conductor.



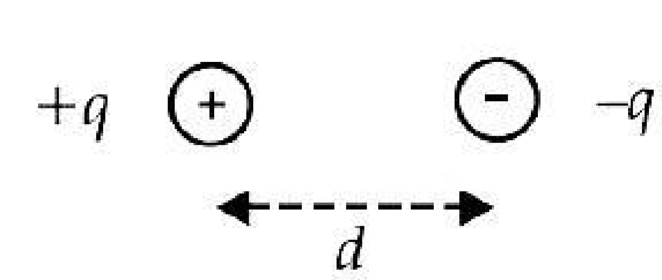
Electric field lines

- Electric field lines are imaginary lines which originates from the positive charge and towards negative charge.
- Direction of electric field lines around positive charge is imagined by positive test charge q_0 located around source charge.
- Electric field has same direction as force on positive test charge.
- Electric field lines linked with negative charge are directed inward described by force on positive test charge q_0.
- The electric field lines never intersect each other.
- Strength of electric field is encoded in density of field lines.



Electric Dipole

- The system formed by two equal and opposite charges separated by a small distance is called an electric dipole.
- The electric field exists due to a dipole.

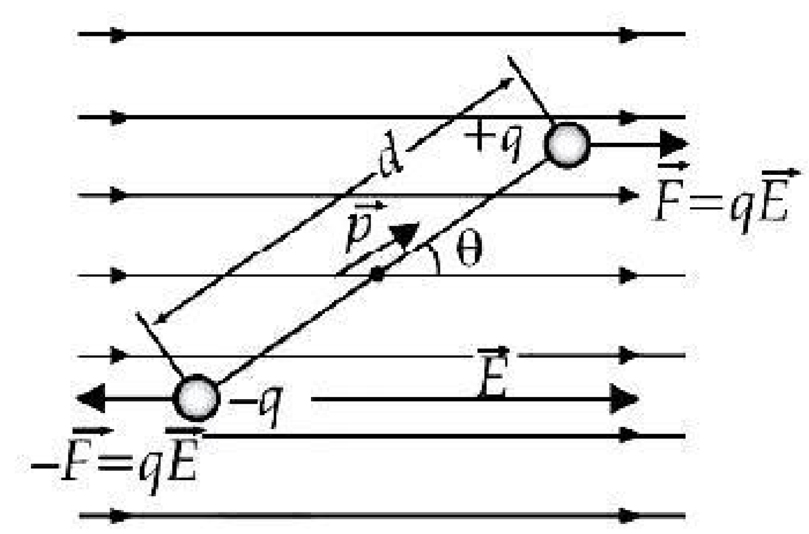


- The force on a dipole in a uniform electric field is zero in both stable as well as unstable equilibrium.
- The potential energy of a dipole in an uniform electric field is minimum for a stable equilibrium and maximum for an unstable equilibrium.

Torque on a dipole

- In a dipole, when net force on dipole due to electric field is zero and center of mass of dipole remains fixed, the forces on charged ends produce net torque τ about its center of mass.

$$\tau = F\,d\sin\theta = qE\,d\sin\theta = pE\sin\theta$$
$$\vec{\tau} = \vec{p}\times\vec{E}$$



  - If $\theta = 0°$ or $360°$, dipole exists in stable equilibrium state.
  - If $\theta = 180°$, dipole exists in an unstable equilibrium state.
- In uniform electric field, dipole experiences torque, net force on dipole is zero.
- In uniform electric field, dipole experiences a rotatory motion.
- In non-uniform electric field, dipole experiences torque and net force.
- In non-uniform electric field, dipole experiences rotatory and translatory motion.
  - The torque aligns dipole with electric field and it becomes zero.
  - The direction of torque is normal to the plane going inward.

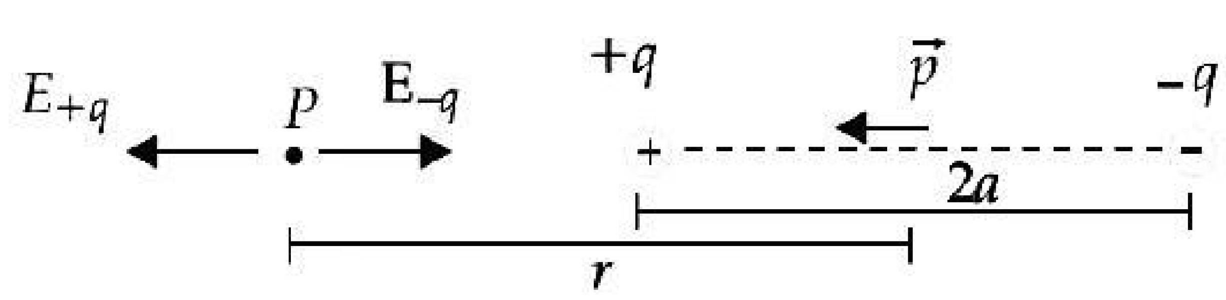
Electric Dipole Moment

- Dipole moment is a vector quantity whose unit is coulomb-metre (Cm).
- Dipole moment vector of electric dipole is $\vec{p} = \vec{q}\times 2a$ between pair of charges q, $-q$, along the line, separated by distance $2a$.

Electric field due to a dipole

- For point P at distance r from centre of dipole on charge q, for $r >> a$, total field at point P is

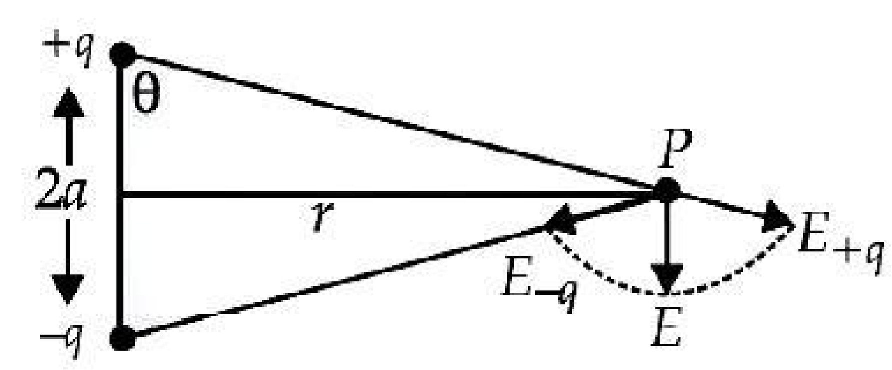
$$E = \frac{4qa}{4\pi\varepsilon_0 r^3}$$



$$= \frac{1}{4\pi\varepsilon_0}\cdot\frac{2p}{r^3} \text{ (if } a << r)$$

- For point P on the equatorial plane due to charges $+q$ and $-q$, electric field of dipole at a large distance,

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



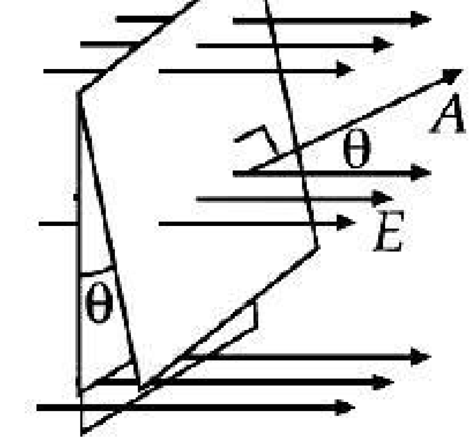
Gauss's Theorem and its Applications

Electric Flux

- Electric flux is proportional to algebraic number of electric field lines passing through the surface, outgoing lines with positive sign, incoming lines with negative sign.
- Due to arbitrary arrangement of electric field lines, electric flux can be quantify as $\phi_E = EA$
- If vector A is perpendicular to surface, magnitude of vector A parallel to electric field is $A\cos\theta$

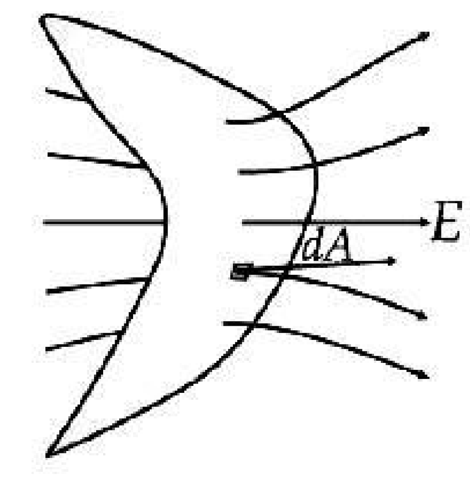
$A_{II} = A\cos\theta$

$\phi_E = EA_{II} = EA\cos\theta$



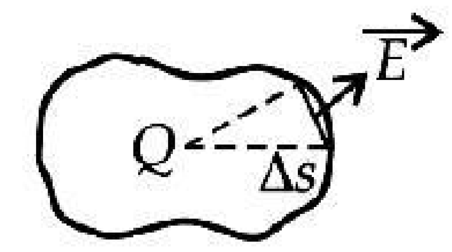
- In non-uniform electric field, the flux will be $\phi_E = \int E dA$

Continuous Charge Distribution



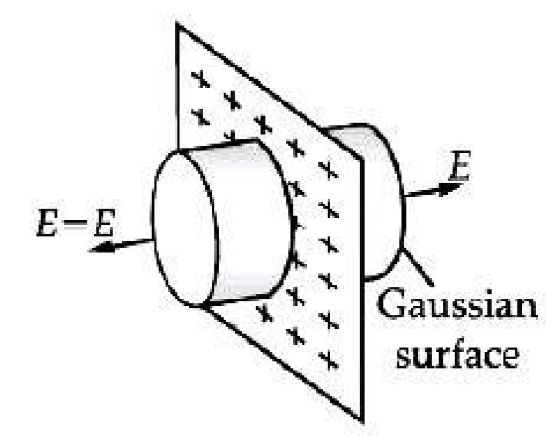
- It is a system in which the charge is uniformly distributed over the material. In this system, infinite number of charges are closely packed and have minor space among them. Unlike the discrete charge system, the continuous charge distribution is uninterrupted and continuous in the material. There are three types of continuous charge distribution system.

- For linear charge distribution (λ), $\vec{F} = \frac{q_0}{4\pi\varepsilon_0}\int_x \frac{\lambda}{r^2} dx\hat{r}$ (Where, λ = linear charge density)
- For surface charge distribution (σ), $\vec{F} = \frac{q_0}{4\pi\varepsilon_0}\int_s \frac{\sigma}{r^2} dS\hat{r}$ (Where, σ = surface charge density)
- For volume charge distribution (ρ), $\vec{F} = \frac{q_0}{4\pi\varepsilon_0}\int_v \frac{\rho}{r^2} dV\hat{r}$ (Where, ρ = volume charge density)



Gauss theorem

- The net outward normal electric flux through any closed surface of any shape is equal to $1/\varepsilon_0$ times to net charge enclosed by the surface.
- The electric field flux at all points on Gaussian surface is $\phi = E\oint dA = \frac{q}{\varepsilon_0}$
- If there is a positive flux, net positive charge is enclosed.
- If there is a negative flux, net negative charge is enclosed.
- If there is zero flux, no net charge is enclosed.
- The expression for electric field due to a point charge on Gaussian surface is $E = \frac{q}{4\pi\varepsilon_0 r^2}$
- In an insulating sheet, charge remains in the sheet, so electric field, $E = \frac{\sigma}{2\varepsilon_0}$
- Gauss theorem works in cases of cylindrical, spherical and rectangular symmetries.
- The field outside the wire points radially outward which depends on distance from wire, $\vec{E} = \frac{\lambda}{2\pi\varepsilon_0 r}\hat{n}$, where, λ is linear density of charge.



- Closed surface : It is a surface which divides the space inside and outside region, where one can't move from one region to another without crossing the surface.
- Gaussian surface : It is a hypothetical closed surface having similar symmetry as problem on which we are working.
- Electrostatic Shielding : It is the phenomenon of protecting a certain region of space from external electric field.
- Dielectric : The non-conducting material in which charges are easily produced on the application of electric field is called dielectric. e.g. Air, H_2 gas, glass, mica, paraffin wax, transformer oil, etc.

Mnemonics

Concept: Characteristics of Electric field lines

Mnemonics: India Starts Playing Night Cricket Tournament Daily with New Inspiration.

How to remember all the 5 characteristics ?

Remember this sentence.

India Starts Playing Night Cricket Tournament Daily with New Inspiration.

- India → Imaginary line
- Starts → Start from
- Playing → Positive charge
- Night → Never forms
- Cricket → closed loops
- Tournament → Tangent at any point
- Daily → Direction of field
- New → Never
- Inspiration → Intersects

Know the Terms

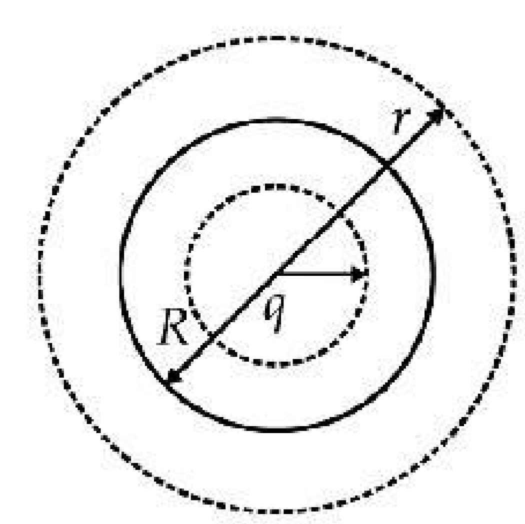
- 1 coulomb: When two point charges placed at a distance of 1 m in vacuum, repel/attract each other with force of 9×10^9 N, the charge on each is known as 1 coulomb.
- Electric line of force: It is a curve drawn in such a way that the tangent at each point to curve gives the direction of the net field at that point.

Know the Formulae

- Coulomb's force: $F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$;

  where all alphabets have their usual meanings.

- Electric field due to point charge q: $E = \frac{k|q|}{r^2} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{r^2}$
- Electric field due to a dipole at a point on the dipole axis: $E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2p}{r^3}$ $(r >>> a)$
- Electric field at a point on equatorial plane: $E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{p}{r^3}$ $(r >>> a)$
- Torque on an electric dipole placed in an electric field, $\tau = pE\sin\theta$
- Electric flux through an area A: $\phi = E.A = EA\cos\theta$
- Electric flux through a Gaussian surface: $\phi = \oint E.dS$
- Gauss's Law: $\phi = \frac{q_{enc}}{\varepsilon_0}$

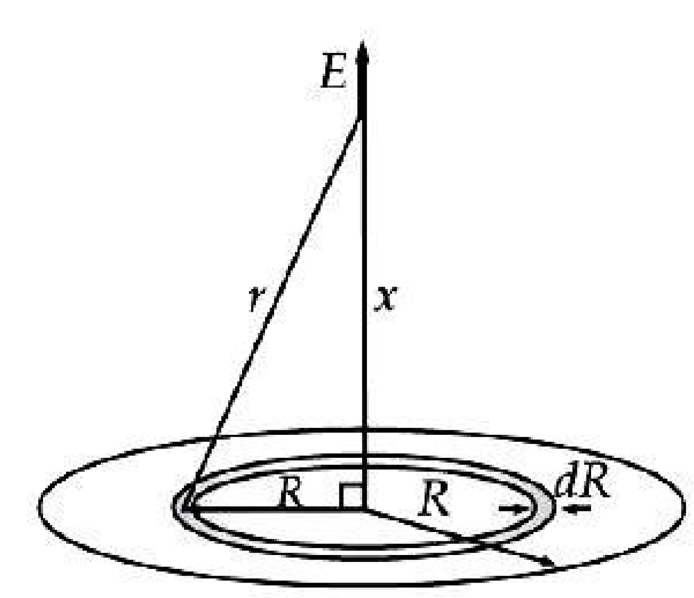


- Electric Field due to an infinite line of charge: $E = \frac{\lambda}{2\pi\varepsilon_0 r} = \frac{2k\lambda}{r}$

  where, E = electric field [N/C], λ = charge per unit length [C/m]

  ε_0 = permittivity of free space = 8.85×10^{-12} [$C^2/N\,m^2$], r = distance (m), $k = 9 \times 10^9$ N m^2 C^{-2}

- Electric field due to a ring at a distance x is: $E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{qx}{(r^2 + x^2)^{3/2}}$



- When, $x >>> r$: $E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{x^2}$
- When $x <<< r$: $E = 0$
- Electric field due to a charged disc: $E = \frac{\sigma}{2\varepsilon_0}\left[1 - \frac{x}{\sqrt{R^2 + x^2}}\right]$

  where ,

  E = electric field [N/C] | σ = charge per unit area [C/m^2]

  $\varepsilon_0 = 8.85 \times 10^{-12}$ [C^2/Nm^2] | x = distance from charge [m]

  R = radius of the disc [m]

- Electric field due to a thin infinite sheet: $\vec{E} = \frac{\sigma}{2\varepsilon_0}\hat{n}$

STAND ALONE MCQs (1 Mark each)

Q. 1. Plastic rod rubbed with fur and glass rod rubbed with silk

(A) repel each other

(B) mix up with each other

(C) attract each other

(D) None of the above

Ans. Option (C) is correct.

> *Explanation:* Rubbing a rod with certain materials will cause the rod to become charged. A plastic rod when rubbed with fur becomes negatively charged and a glass rod when rubbed with silk becomes positively charged.

Q. 2. Electric charge between two bodies can be produced by

(A) sticking **(B)** rubbing

(C) oiling **(D)** passing AC current

Ans. Option (B) is correct.

> *Explanation:* The tribo-electric effect is a type of contact electrification on which certain materials become electrically charged after they come into frictional contact with a different material.

Q. 3. Electric charges under action of electric forces is called

(A) electrostatic **(B)** electric flux

(C) electric field **(D)** electric field lines

Ans. Option (A) is correct.

> *Explanation:* Coulomb force, also called electrostatic force or Coulomb interaction, attraction or repulsion of particles or objects because of their electric charge.

Q. 4. Law stating that "force is directly proportional to product of charges and inversely proportional to square of separation between them" is called

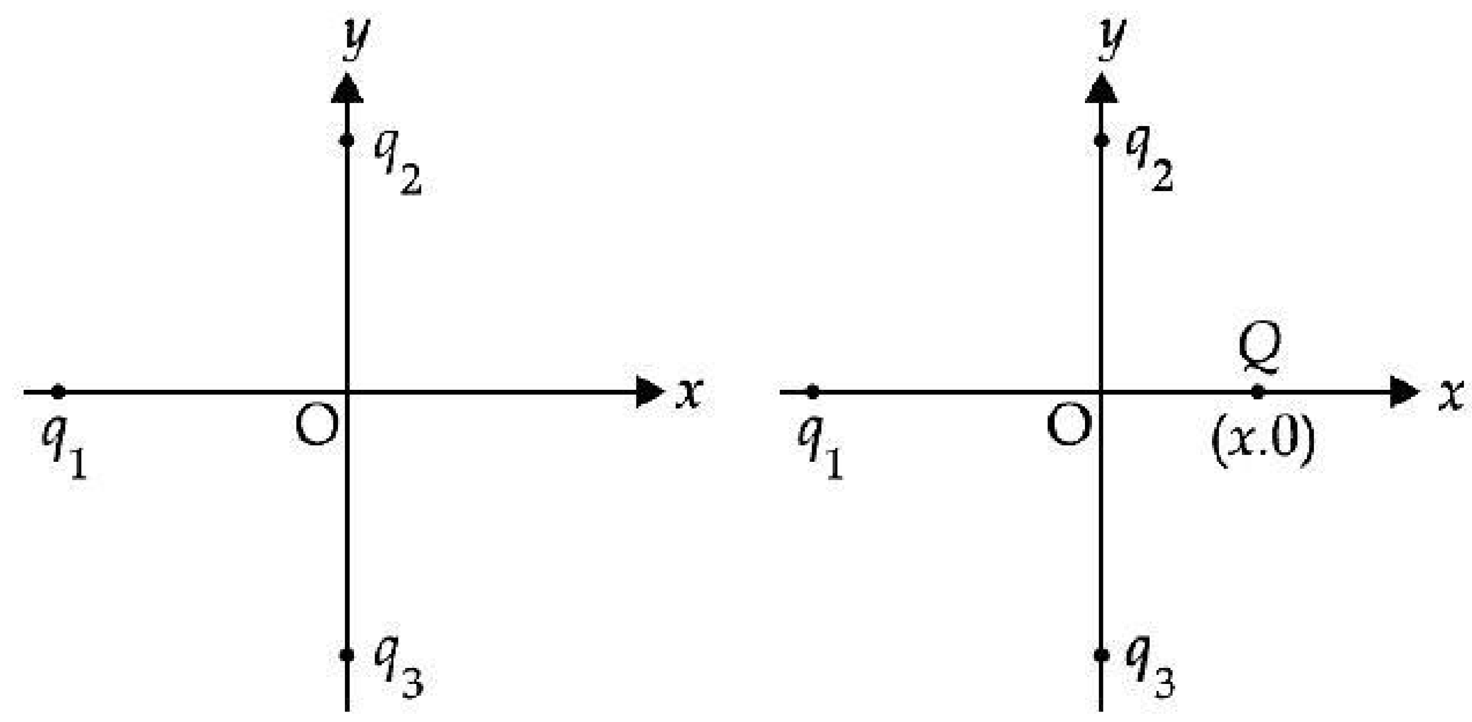
(A) Newton's law. **(B)** Coulomb's law

(C) Gauss's law. **(D)** Ohm's law

Ans. Option (B) is correct.

> *Explanation:* Coulomb's law states that : The magnitude of the electrostatic force of attraction or repulsion between two-point charges is directly proportional to the product of the magnitudes of charges and inversely proportional to the square of the distances between them.

Q. 5. In given figure, two positive charges q_2 and q_3 fixed along the y axis, exert a net electric force in the + x direction on a charge q_1 fixed along the x axis. If a positive charge Q is added at $(x, 0)$, the force on q_1



(A) shall increase along the positive x-axis.

(B) shall decrease along the positive x-axis.

(C) shall point along the negative x-axis.

(D) shall increase but the direction changes because of the intersection of Q with q_2 and q_3.

Ans. Option (A) is correct.

> *Explanation:* Net force on charge q_1, by other charges q_2 and q_3 is along the + x-direction, so nature of force between q_1 and q_2 and q_1 and q_3 is attractive. This is possible when charge q_1 is negative. Now, if a positive charge Q is placed at $(x, 0)$, then, the force on q_1 will increase. The direction will be along positive x-axis.

Q. 6. The magnitude of electric force, F is

(A) directly proportional to the multiplication of both charges.

(B) directly proportional to the distance between both charges.

(C) directly proportional to the square of the distance between both charges.

(D) constant.

Ans. Option (A) is correct.

> *Explanation:* The magnitude of the electric force F is directly proportional to the amount of an electric charge, q_1, multiplied by the other, q_2, and inversely proportional to the square of the distance 'r' between their centres.

Q. 7. A body is negatively charged means

(A) It has only negative charges.

(B) Positive charges have been neutralized by negative charges.

(C) The quantity of negative charge present is more than the quantity positive charge present.

(D) The positive are displaced from their original positions.

Ans. Option (C) is correct.

> *Explanation:* When a neutral body gains electrons, it becomes negatively charged. It means that the quantity of negative charges present is more than the quantity of positive charge present.

Q. 8. When a body is charged by conduction, its mass

(A) remains same. (B) increases.

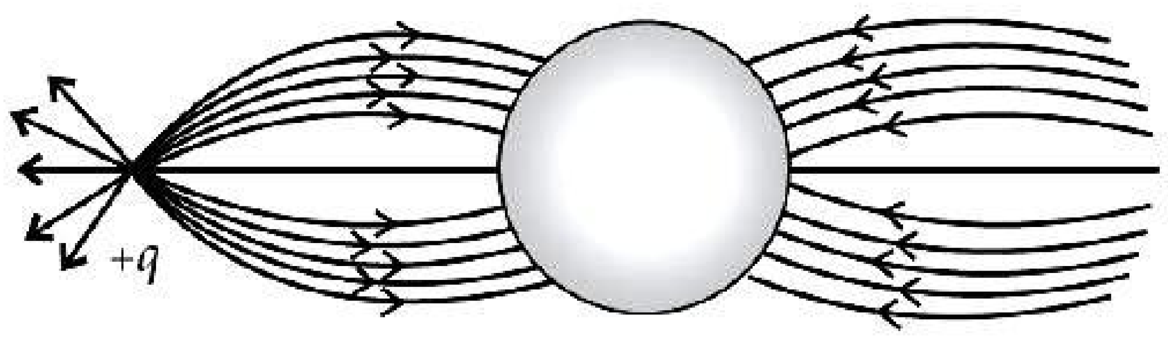
(C) decreases. (D) increase or decrease.

Ans. Option (D) is correct.

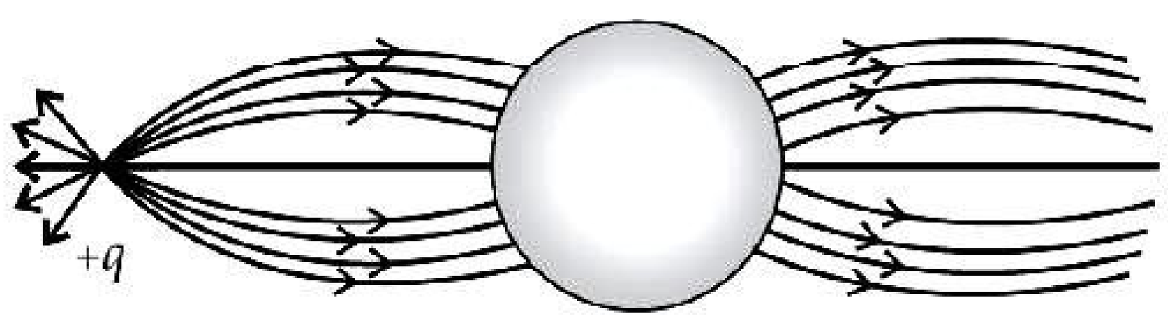
> *Explanation:* When a body is negatively charged by conduction, it gains electrons. Hence, its mass increases. When a body is positively charged by conduction, it loses electrons. Hence, its mass decreases.

Q. 9. A point positive charge is brought near an isolated conducting sphere in Figure. The electric field is best given by :

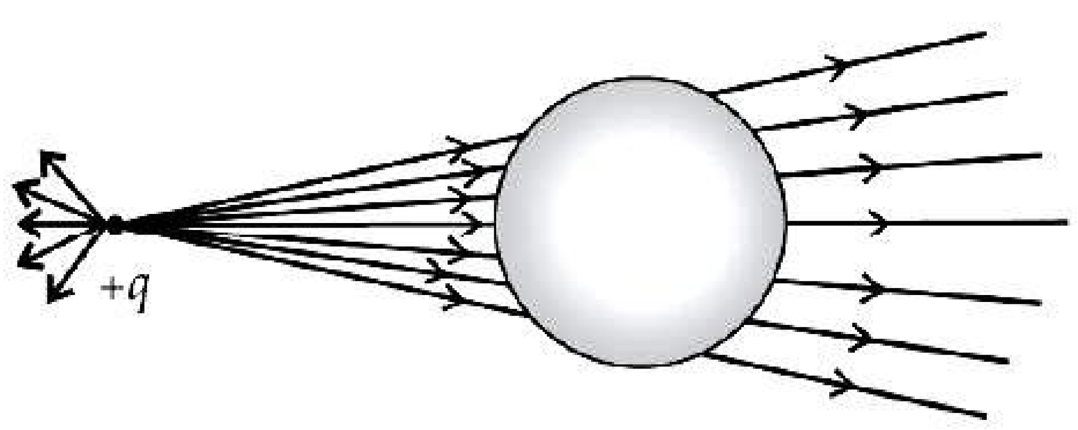
(i)



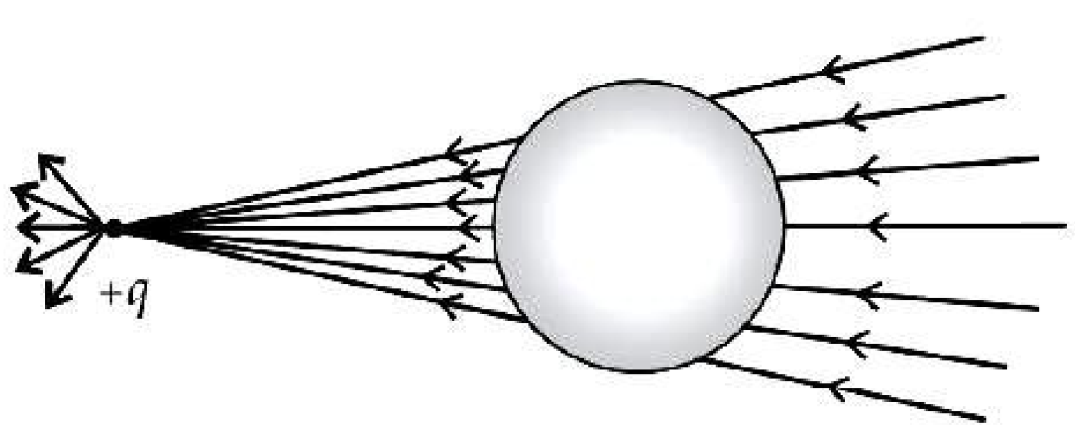
(ii)



(iii)



(iv)



(A) Fig (i) (B) Fig (iii)

(C) Fig (ii) (D) Fig (iv)

Ans. Option (B) is correct.

> *Explanation:* As given charge is + q and lines of forces in positive charge must be outwards from positive charge q. Now, as the positive charge is kept near an isolated conducting sphere, due to induction, left part of sphere gets accumulated negative charge and right part gets positive, and lines of force from right part of sphere must emerge outwards normally.
>
> So, verifies the answer (B)
>
> As lines of forces are not perpendicular to the surface of sphere, so options (iii) and (iv) are not true again. Hence option (C) is not correct.

Q. 10. A point charge $+q$, is placed at a distance d from an isolated conducting plane. The field at a point P on the other side of the plane is

(A) directed perpendicular to the plane and away from the plane.

(B) directed perpendicular to the plane but towards the plane.

(C) directed radially away from the point charge.

(D) directed radially towards the point charge.

Ans. Option (A) is correct.

> *Explanation:* When you place a positive charge near a conducting plane, then electric field lines from positive charges will enter into the conducting plane (from the side where positive charge is kept) and emerge from opposite side of the plane.
>
> In both cases, the direction of electric field lines will always be perpendicular to the surface of the plane.

Q. 11. A hemisphere is uniformly charged positively. The electric field at a point on a diameter away from the centre is directed

(A) perpendicular to the diameter.

(B) parallel to the diameter.

(C) at an angle tilted towards the diameter.

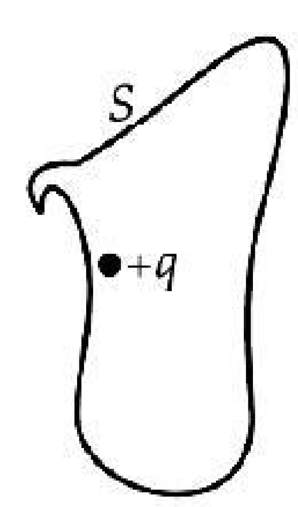
(D) at an angle tilted away from the diameter.

Ans. Option (A) is correct.

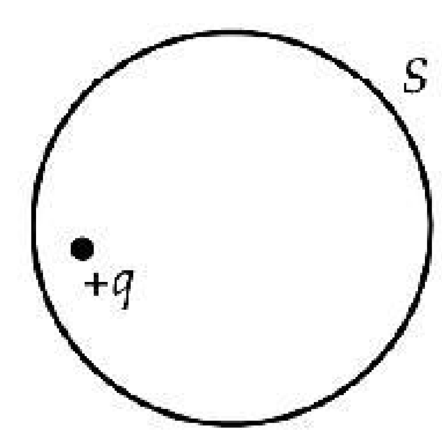
> *Explanation:* As the side or diameter of hemisphere is plane surface, and whole hemisphere is charged with positive charge so, the electric field line of forces emerging outward will be perpendicular to the plane surface or diameter.

Q. 12. The electric flux through the surface :

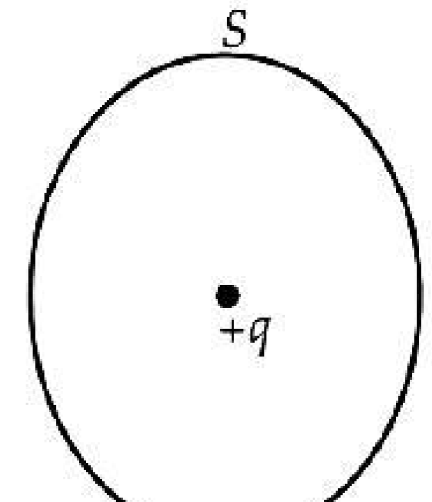
(i)



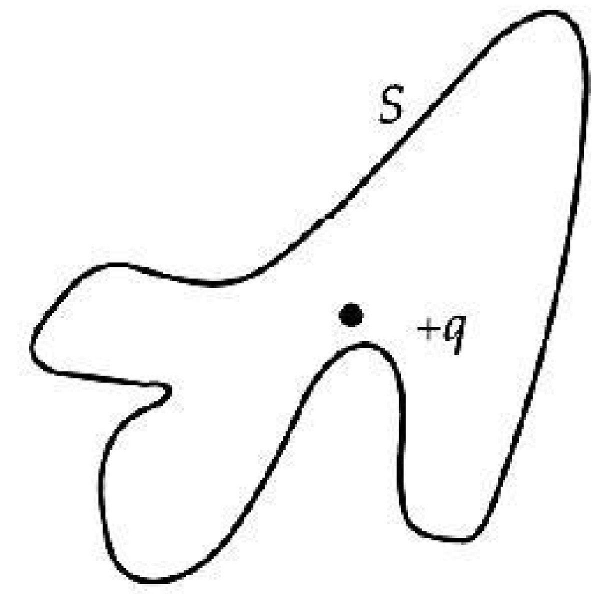
(ii)



(iii)



(iv)



(A) in Figure (iv) is the largest.

(B) in Figure (iii) is the least.

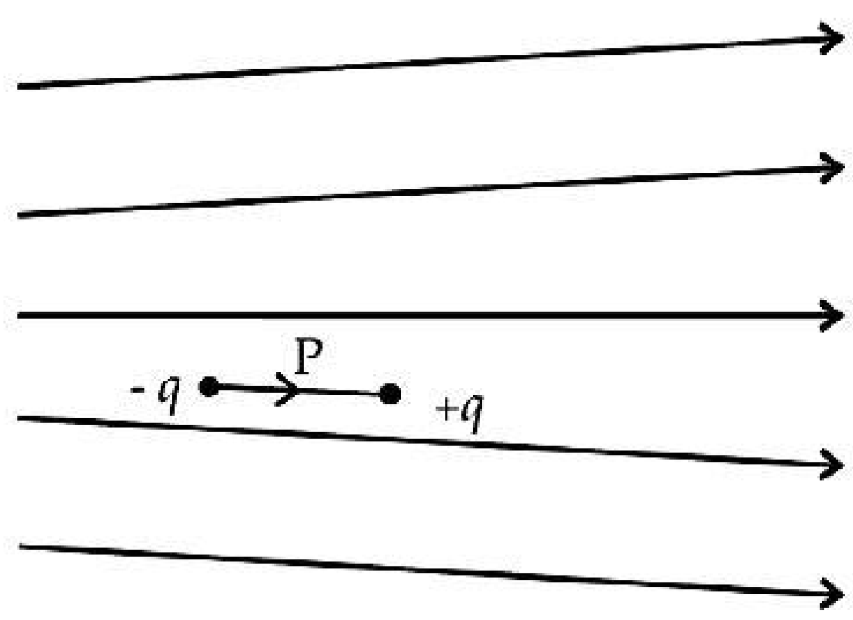
(C) in Figure (ii) is same as Figure (iii) but is smaller than Figure (iv).

(D) is the same for all the figures.

Ans. Option (D) is correct.

Explanation: Electric flux, through the closed surface (or space) depends only on the charge enclosed inside the surface. Here, charges inside all figures are same. So, electric flux will remain same.

Q. 13. Figure shows electric field lines in which an electric dipole p is placed as shown. Which of the following statements is correct?



(A) The dipole will not experience any force.

(B) The dipole will experience a force towards right.

(C) The dipole will experience a force towards left.

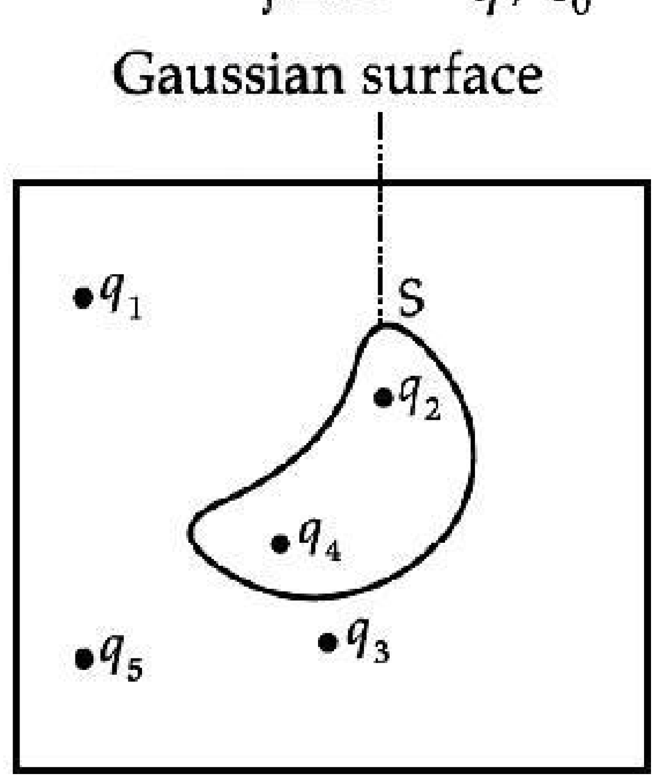
(D) The dipole will experience a force upwards.

Ans. Option (C) is correct.

Explanation: We know electric field emerges radially outward from positive point charge.
In the figure given above, space between field lines is increasing (or density of electric field line is decreasing). In other words, the electric force is decreasing while moving from left to right.
Thus, the force on charge $-q$ is greater than the force on charge $+q$ and in turn, dipole will experience a force towards left direction.

Q. 14. Five charges q_1, q_2, q_3, q_4, and q_5 are fixed at their positions as shown in Figure. S is a Gaussian surface. The Gauss's law is given by:

$$\oint E.ds = q / \varepsilon_0$$



Which of the following statements is correct?

(A) E on the LHS of the above equation will have a contribution from q_1, q_5 and q_3, while q on the RHS will have a contribution from q_2 and q_4 only.

(B) E on the LHS of the above equation will have a contribution from all charges, while q on the RHS will have a contribution from q_2 and q_4 only.

(C) E on the LHS of the above equation will have a contribution from all charges, while q on the RHS will have a contribution from q_1, q_3 and q_5 only.

(D) Both E on the LHS and q on the RHS will have contributions from q_2 and q_4 only.

Ans. Option (B) is correct.

Explanation: As all charges are positive (or of same signs), so electric field lines on R.H.S. of Gaussian surface will be due to q_2 and q_4 only. On L.H.S. of Gaussian surface, the electric field lines on 'E' will be due to q_1, q_2, q_3, q_4 and q_5. So, answer (B) is verified.

Q. 15. The Electric field at a point is

(A) always discontinuous.

(B) discontinuous if there is a positive charge at that point.

(C) discontinuous only if there is a negative charge at that point.

(D) discontinuous if there is a charge at that point.

Ans. Option (D) is correct.

Explanation: Either positive or negative charge will interact with the lines of electric field, so the electric field will become discontinuous.

Q. 16. If there is only one type of charge in the universe, then

(A) $\oint E.ds \neq 0$ on any surface.

(B) $\oint E.ds = \varepsilon_0/q$ if the charge is outside the surface.

(C) $\oint E.ds$ cannot not be defined.

(D) $\oint E.ds = q/\varepsilon_0$ if charges of magnitude q is inside the surface.

Ans. Option (D) is correct.

Explanation: If a charge q is enclosed inside Gaussian surface then according to Gauss law $\oint E.ds = q/\varepsilon_0$.

ASSERTION AND REASON BASED MCQs (1 Mark each)

Directions : In the following questions, A statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as.

(A) Both A and R are true and R is the correct explanation of A

(B) Both A and R are true but R is NOT the correct explanation of A

(C) A is true but R is false

(D) A is false and R is true

Q. 1. Assertion (A): In a non-uniform electric field, a dipole will have translatory as well as rotatory motion.

Reason (R): In a non-uniform electric field, a dipole experiences a force as well as torque.

Ans. Option (A) is correct.

> *Explanation:* When an electric dipole is placed in a uniform electric field at an angle θ with the field, the dipole experiences a torque.
> The torque produced by two parallel forces qE acting as couple = τ
> $\tau = q\text{E}\,(2l\sin\theta)$
> In case of non-uniform field, force acting on both the ends of the dipole will not be equal. So, there will be a combination of couple and a net force. In this way, dipole will have both rotational as well as linear motion.
> So, both assertion and reason are true. Reason also explains the assertion.

Q. 2. Assertion (A): The basic difference between magnetic lines of force and electric lines of force is electric lines of force are discontinuous and magnetic lines of force are continuous.

Reason (R): Magnetic lines of force exist in a magnet but no electric lines of force exists in a charged body.

Ans. Option (A) is correct.

> *Explanation:* Let us consider an electric dipole. The electric lines of force exists outside only and not inside the dipole.
> Let us now consider a magnetic dipole. The magnetic lines of force exist outside as well as inside the dipole.
> So, it can be said that magnetic lines of force are continuous and electric lines of force are discontinuous.
> So assertion and reason both are true and reason explains the assertion too.

Q. 3. Assertion (A): Electric lines of force cross each other.

Reason (R): The resultant electric field at a point is the superimposition of the electric fields at that point.

Ans. Option (D) is correct.

> *Explanation:* Electric lines of force never cross each other. If they cross each other, then at that point, we get two directions of electric field at that point, which is not possible. So, the assertion is false. The resultant electric field at a point is a vector sum of the electric fields at that point.

Q. 4. Assertion (A): When bodies are charged through friction, there is transfer of charge from one body to another. No charge is created or destroyed.

Reason (R): This is according to the law of conservation of electric charge.

Ans. Option (A) is correct.

> *Explanation:* When two bodies are rubbed, electrons move from one body to another. The body which loses electrons becomes positively charged. The body which receives the electron becomes negatively charged. So, the assertion is true.
> Law of conservation of electric charge states that electric charge can neither be created nor destroyed. In a closed system, the amount of charge remains same. Hence the reason is also true and properly explains the assertion.

Q. 5. Assertion (A): If two spherical conductors of different radii have the same surface charge densities, then their electric field intensities will be equal.

Reason (R): Surface charge density = $\frac{\text{Total charge}}{\text{area}}$

Ans. Option (B) is correct.

> *Explanation:* If σ be the surface charge density of the two spheres of radius r and R, then electric fields for the two spheres are respectively:
> $$E_1 = \frac{\kappa 4\pi r^2\sigma}{r^2} = \kappa 4\pi\sigma$$
> $$E_2 = \frac{\kappa 4\pi R^2\sigma}{R^2} = \kappa 4\pi\sigma$$
> So electric field intensities are equal. The assertion is true.
> Surface charged density is charge per unit area = Total charge/area.
> So reason is also true.
> But the reason does not explain the assertion.

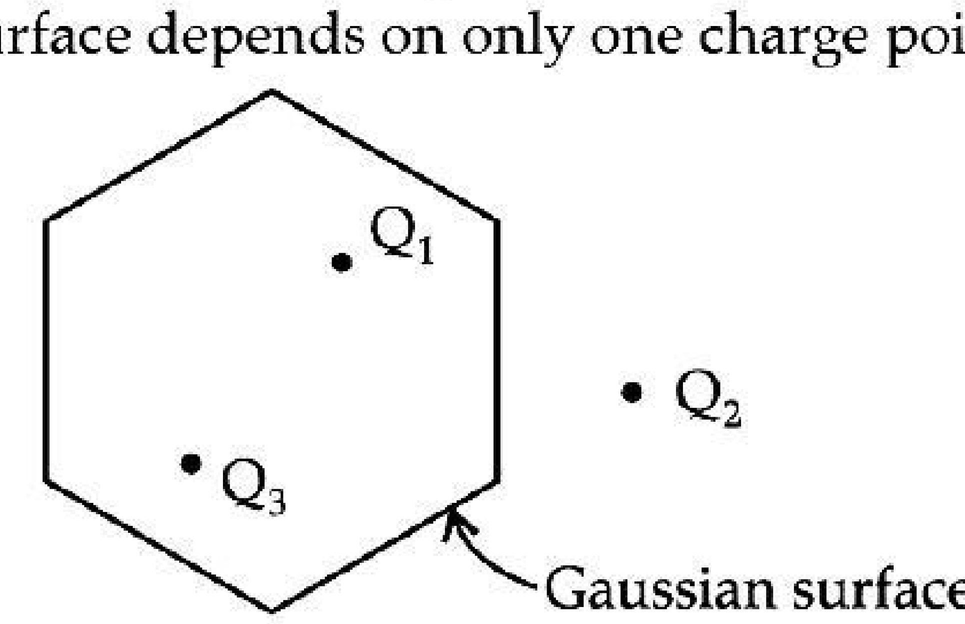
Q. 6. Assertion (A): In a cavity in a conductor, the electric field is zero.

Reason (R): Charges in a conductor reside only at its surface.

Ans. Option (A) is correct.

> *Explanation:* The charge enclosed by the Gaussian surface surrounding the cavity is zero. Hence, the electric field is also zero. So, the assertion is true.
> Charges in a conductor reside only at its surface. So, in cavity there is no charge. So, the reason is also true and properly explains the assertion.

Q. 7. Assertion (A): Three point charges Q_1, Q_2 and Q_3 are shown in the figure. The flux over the Gaussian surface depends on only one charge point.



Reason (R): Electric flux depends on the all charges nearby.

Ans. Option (D) is correct.

Explanation: According to Gauss's law, electric flux depends on the enclosed charges only. Here the enclosed charges are Q_1 and Q_3 only. Hence the assertion is false and the reason is true.

Q. 8. Assertion (A): Using Gauss law, it is possible to find the electric field at any point.

Reason (R): Gauss law is applicable for any type of charge distribution.

Ans. Option (C) is correct.

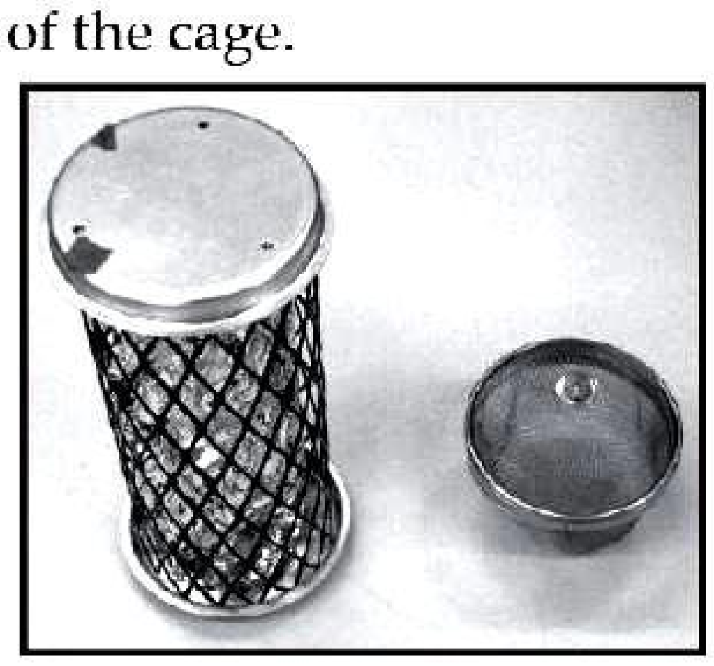
Explanation: Considering suitable Gaussian surface, we can easily find the electric field at any point. So, the assertion is true.
But it is very very difficult to apply Gauss law, if the charge distribution is so that the Gaussian surface is complicated in shape. So, reason is false.

CASE-BASED MCQs

Attempt any 4 sub-parts out of 5. Each sub-part carries 1 mark.

I. Read the following text and answer the following questions on the basis of the same:

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



Q. 1. Which of the following material can be used to make a Faraday cage ?

(A) Plastic (B) Glass
(C) Copper (D) Wood

Ans. Option (C) is correct.

Explanation: A Faraday cage or Faraday shield is an enclosure made of a conducting material. Since copper is the only metal given in the list of options, copper is the correct answer.

Q. 2. Example of a real-world Faraday cage is :

(A) car (B) plastic box
(C) lighting rod (D) metal rod

Ans. Option (A) is correct.

Explanation: Cars are example of Faraday Cages in the real world. Cars can help keep us safe from lightning. Its metal body acts as a Faraday Cage.

Q. 3. 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

Ans. Option (C) is correct.

Explanation: The field within a conductor cancel out with any external fields, so the electric field within the enclosure is zero.

Q. 4. If isolated point charge $+q$ is placed inside the Faraday cage. Its surface must have charge equal to :

(A) Zero (B) $+q$
(C) $-q$ (D) $+2q$

Ans. Option (C) is correct.

Explanation: If a charge is placed inside an ungrounded Faraday shield without touching the walls of the internal face of the shield becomes charged with $-q$, and $+q$ accumulates on the outer face of the shield. If the cage is grounded, the excess charges will be neutralized by the ground connection.

Q. 5. A point charge of 2 C is placed at centre of Faraday cage in the shape of cube with surface of 9 cm edge. The number of electric field lines passing through the cube normally will be :

(A) 1.9×10^5 Nm^2/C entering the surface.
(B) 1.9×10^5 Nm^2/C leaving the surface.
(C) 2.0×10^5 Nm^2/C leaving the surface.
(D) 2.0×10^5 Nm^2/C entering the surface.

Ans. Option (D) is correct.

Explanation: The number of electric field lines passing through the cube normally and leaving the surface = Q/ε_0

$$Q = 2\,\mu C = 2 \times 10^{-6}\ C$$
$$\varepsilon_0 = 8.85 \times 10^{-12}\ C^2/Nm^2$$
$$\therefore \quad Q/\varepsilon_0 = 2.2 \times 10^5\ C^2/Nm^2$$

II. Read the following text and answer the following questions on the basis of the same:

Triboelectric series:

The triboelectric series is a list that ranks materials according to their tendency to gain or lose electrons. The process of electron transfer as a result of two objects coming into contact with one another and then separating is called triboelectric charging. During such an interaction, one of the two objects will always gain electrons (becoming negatively charged) and the other object will lose electrons (becoming positively charged). The relative position of the two objects on the triboelectric series will define which object gains electrons and which object loses electrons.

In triboelectric series, materials are ranked from high to low in terms of the tendency for the material to lose electron. If an object high up on this list (Glass, for example) is rubbed with an object low down on the list (Teflon, for example), the glass will lose electrons to the teflon. The glass will, in this case, become positively charged and the teflon will become negatively charged. Materials in the middle of the list (steel and wood, for example) are items those do not have a strong tendency to give up or accept electrons.

Tend to lose electrons

↑

Human hand
Glass
Human hair
Nylon
Cat fur
Silk
Cotton
Steel
Wood
Amber
Ebonite
Plastic wrap
Teflon

↓

Tend to gain electrons

Q. 1. Materials in the upper position has _____ tendency to become positively charged.

(A) low **(B)** high

(C) no **(D)** medium

Ans. Option (B) is correct.

> *Explanation:* In triboelectric series, materials are ranked from high to low in terms of the tendency for the material to lose electron i.e. they are ranked high to low tendency of getting positively charged.

Q. 2. Name two materials which do not have a strong tendency to give up or accept electrons.

(A) Ebonite, Nylon **(B)** Plastic wrap, Teflon

(C) Nylon, cat fur **(D)** Steel, wood

Ans. Option (D) is correct.

> *Explanation:* Materials in the middle of the list (steel and wood, for example) are items those do not have a strong tendency to give up or accept electrons.

Q. 3. If human hair is rubbed with amber, how those will be charged?

(A) Both negative

(B) Both positive

(C) Hair will be positively charged, Amber will be negatively charged.

(D) Hair will be negatively charged, Amber will be positively charged.

Ans. Option (D) is correct.

> *Explanation:* Since human hair is placed at the upper portion of the list, it will leave electron and will be positively charged. Since amber is placed at the lower portion of the list, it will accept the electron and will be negatively charged.

Q. 4. Triboelectric charging is the process of electron transfer between two objects

(A) By contact

(B) Without contact

(C) By any one of the above

(D) By none of the above

Ans. Option (A) is correct.

> *Explanation:* The process of electron transfer as a result of two objects coming into contact with one another and then separating is called triboelectric charging.

Q. 5. The object which loses electron becomes _____ charged and the object gains electron becomes ______ charged.

(A) negatively, negatively

(B) positively, positively

(C) positively, negatively

(D) negatively, positively

Ans. Option (C) is correct.

> *Explanation:* During triboelectric charging, one of the two objects always gains electrons and become negatively charged. The other object loses electrons and become positively charged.