NEET Revision Notes
Physics
Electric Charges and Fields

Electric charge:

Charge is the property associated with matter due to which it produces and experiences electrical and magnetic effects. The excess or deficiency of electrons in a body gives the concept of charge.

Properties of charge:

- Charge is a scalar quantity.
- Charge is transferable: If a charged body is put in contact with an uncharged body, the uncharged body becomes charged due to transfer of electrons from one body to the other.
- Charge is always associated with mass, i.e., charge cannot exist without mass though mass can exist without charge. So, the presence of charge itself is a convincing proof of existence of mass.

Quantization of charge: Total charge on a body is always an integral multiple of a basic unit of charge denoted by e and is given by q = ne,
where n is any integer, positive or negative and e $=1.6\times10^{-19}$C

- The quantization of charge was first suggested by Faraday. It was experimentally demonstrated by Millikan in 1912.
- The basic unit of charge is the charge that an electron or proton carries. By convention the charge on electron is -e($-1.6\times10^{-19}C$) and charge on proton is +e($1.6\times10^{-19}C$).
- **Additivity of charge:** Total charge of a system is the algebraic sum (i.e. Sum is taking into account with proper signs) of all individual charges in the system.
- **Conservation of charge:** Total charge of an isolated system remains unchanged with time.
- **Charge is invariant:** Charge is independent of the frame of reference.
- Like charges repel each other while unlike charges attract each other.

Methods of charging: A body can be charged by

Friction: This is the process of charging two non-conducting bodies by rubbing them vigorously. By this transfer of electrons takes place between the charged bodies.

Induction: This method of charging charges an object without actually touching the object.

Conduction: This method of charging charges a neutral object with a charged object.

Coulomb's law:

It states that **"The electrostatic force of interaction (repulsion or attraction) between two electric charges q_1 and q_2 separated by a distance R is directly proportional to the product of the charges and inversely proportional to the square of the distance between them and act along the straight line joining two charges."**

i.e., $F = K\frac{q_1 q_2}{r^2}$ where $K = \frac{1}{4\pi\varepsilon_0} = 9\times10^9 Nm^2C^{-2}$ is the proportionality constant and $E = \frac{\sigma}{\varepsilon_0}$, $\varepsilon_0 = 8.854\times10^{-12}C^2N^{-1}m^{-1}$ is permittivity of free space.

Coulomb's law in vector form:

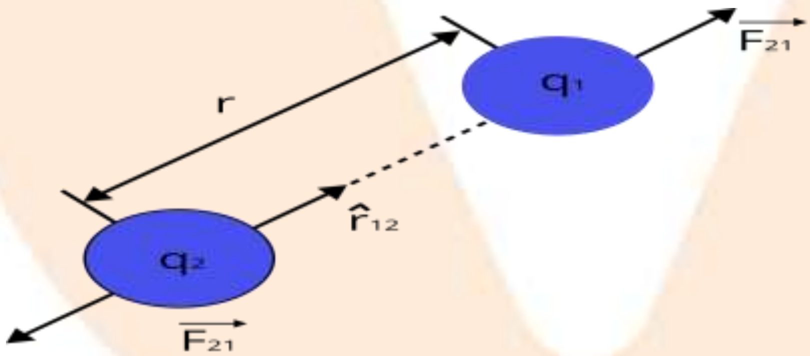

Image: Coulomb's law in vector form

$\vec{F}_{12}$ = force on q_1 due to q_2

$= K\frac{q_1 q_2}{r^2}\hat{r}_{21}$

$\vec{F}_{21} = K\frac{q_1 q_2}{r^2}\hat{r}_{21}$

= force on q_2 due to q_1.

Here, $\hat{r}_{12}$ is unit vector from q_1 to q_2.

Coulomb's law in terms of positive vector: $\vec{F}_{21} = K \frac{q_1 q_2}{|\vec{r}_1 - \vec{r}_2|^3}(\vec{r}_1 - \vec{r}_2)$

The comparison between Coulomb force and gravitational force is as follows:

Coulomb force and gravitational force follow the same inverse square law. Coulomb force can be attractive or repulsive while gravitational force is always attractive. Coulomb force between the two charges depends on the medium between two charges while gravitational force is independent of the medium between the two bodies.

The ratio of Coulomb force to the gravitational force between two protons at a same distance apart is $\frac{e^2}{4\pi\varepsilon_0 G m_p m_p} = 1.3 \times 10^{36}$

Principle of superposition of charges:

It states that, when a number of charges are interacting with each other, the total force on a given charge is vector sum of forces exerted on it by all other charges;

i.e., $F = K\frac{q_0 q_1}{r_1^2} + K\frac{q_0 q_2}{r_2^2} + ... + K\frac{q_0 q_n}{r_n^2}$

In vector form, $\vec{F} = Kq_0 \sum_{i=1}^{n} \frac{q_i \vec{r}_i}{r_i^2}$

Continuous charge distribution:

- **Linear charge density:** Charge per unit length is known as linear charge density. It is denoted by symbol $\lambda = \frac{Charge}{Length}$. Its SI unit is Cm^{-1}.
- **Surface charge density:** Charge per unit area is known as surface charge density. It is denoted by symbol $\sigma = \frac{Charge}{Area}$. Its SI unit is Cm^{-2}.

Electric field:

The region surrounding a charge (or charge distribution) in which its electric effects are perceptible is called the electric field of the given charge.

Electric field due to point Charge:

$$\vec{E} = \lim_{q_0 \to 0} \frac{\vec{F}}{q_0} = \frac{kq}{r^3}\vec{r}$$

Here, test charge is a fictitious charge that exerts no force on hereby changes but experiences force due to them.

Electric Field Lines:

- An electric field can be represented and so visualized by electric field lines. These are drawn so that, the field lines at a point, (or the tangent to it if it is curved) gives the direction of $\vec{E}$ at that point, i.e., the direction in which of positive charge would move and the number of lines per unit cross-section area is proportional to E. The field lines are imaginary but the field it represents is real.
- Electric field due to a positive point charge is represented by straight lines originating from the charge.
- The electric field due to a negative point charge is represented by straight lines terminating at the charge.
- The lines of force are purely a geometrical construction which helps us to visualize the nature of the electric field in the region. They have no physical existence.
- The number of lines originating or terminating on a charge is proportional to the magnitude of the charge. In rationalized MKS system:

The number of lines originating or terminating on a charge is proportional to the magnitude of charge. In rationalized MKS system $(1/\varepsilon_0)$ electric lines are associated with unit charge. So if a body encloses a charge q, total lines of force associated with it (called flux) will be q/ε_0.

Electric dipole:

It is a pair of two equal and opposite charges separated by a small distance.

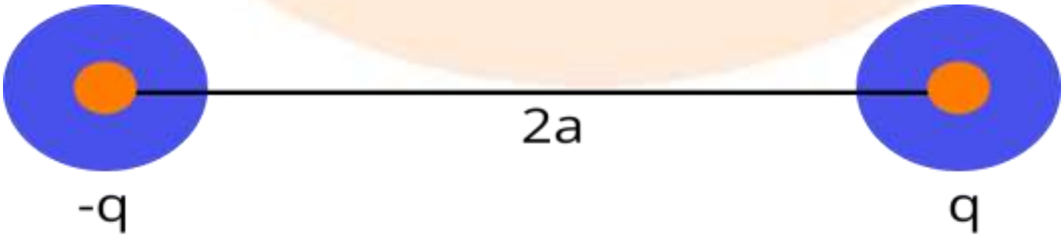

Image: Electric dipole

Electric Dipole Moment:

- It is a vector quantity whose magnitude is equal to product of the magnitude of both charge and distance between the charges. i.e. $|\vec{p}| = q2a$
- By convention the direction of dipole moment is from negative charge to positive charge.
- The SI unit of electric dipole moment is C meter and its dimensional formula is $\left[M^0 LAT\right]$. The practical unit of electric dipole moment is debye.
- **Electric Field Intensity on Axial Line (End on Position) of the Electric Dipole:**
  - At the distance r from the center of the electric dipole, $E = \frac{1}{4\pi\varepsilon_0}\frac{2pr}{(r^2 - a^2)^2}$
  - At very large distance i.e., (r >> a), $E = \frac{2pr}{4\pi\varepsilon_0 r^3}$
  - The direction of the electric field on axial line of the electric dipole is along the direction of the dipole moment (i.e. from -q to q).
- **Electric Field Intensity on Equatorial Line (Board on Position) of Electric Dipole:**
  - At the point at distance r from the center of electric dipole, $E = \frac{1}{4\pi\varepsilon_0}\frac{qr}{\left(r^2 + a^2\right)^{3/2}}$

    At very large distance i.e., $r \gg>$ a,

    $E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$
  - The direction of the electric field on the Equatorial line of the electric dipole is opposite to the direction of the dipole moment.
    (i.e. from q to -q)
- **Electric Field Intensity at any point due to an Electric Dipole:**
  The electric field intensity at point P due to an electric dipole,

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

Electric Field Intensity due to a Charged Ring At a point on its axis at distance r from its center,

$$E = \frac{1}{4\pi\varepsilon_0} \frac{qr}{\left(r^2 + a^2\right)^{3/2}}$$

Where q is the charge on the ring and a is the radius of the ring.
At very large distance i.e. r >>a,
At the center of the ring, i.e. r = 0, E = 0.

- **Torque on an Electric Dipole placed in a uniform Electric Field**
  When an electric dipole of dipole moment $\vec{p}$ is placed in a uniform electric field $\vec{E}$, it will experience a torque and it is given by
  $$\vec{\tau} = \vec{p} \times \vec{E}$$
  $$\tau = pE\sin\theta$$
  Where θ is the angle between p and E.
- Torque acting on a dipole is maximum $(\tau_{\max} = pE)$ When the dipole is perpendicular to the field and minimum(x = 0) when the dipole is parallel or anti-parallel to the field.
- When a dipole is placed in a uniform electric field, it will experience only torque and the net force on the dipole is zero while when it is placed in a non-uniform electric field, it will experience both torque and net force.

Electric flux:

- If the lines of force pass through a surface then the surface is set to have flux linked with it. Mathematically, it can be formulated as follows:
  The flux linked with small area element on the surface of the body
  $$d\phi = \vec{E}.\overrightarrow{ds}$$
  where $d\vec{s}$ is the area vector of the small area element. The area vector of a closed surface is always in the direction of outward drawn normal. The total flux linked with whole of the body $\phi = \oint \vec{E}.d\vec{s}$.
- **Gauss's Theorem:** The total flux linked with a closed surface is $\frac{1}{\varepsilon_o}$ times the charge enclosed by the closest surface (Gaussian surface) i.e., $\oint \vec{E}.d\vec{s} = \frac{q}{\varepsilon_o}$.
  This law is applicable for symmetrical charge distribution and valid for all vector fields obeying inverse square law.

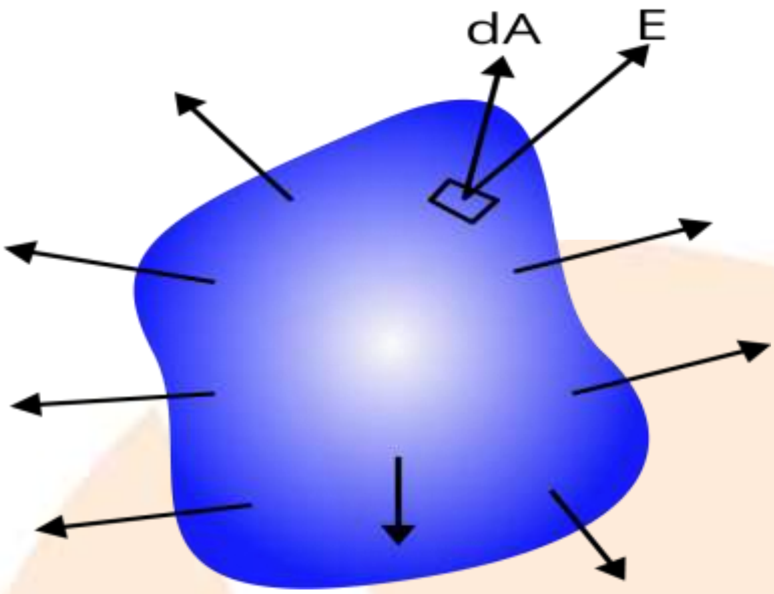

Image: Gauss Theorem

- **Gaussian Surface:**
  a) It is an imaginary surface.
  b) It is spherical for infinite sheet of charge, conducting and non conducting spheres.
  c) It is cylindrical for infinite sheet of charge, conducting charge surfaces, infinite line of charges charged cylindrical conductors etc.

Application of gauss law:

- **Electric field due to an infinitely long thin uniformly charged straight wire:**
  Electric field due to thin infinitely long straight wire of uniform linear charge density is
  $E = \frac{\lambda}{2\pi\varepsilon_0 r}$ where r is the perpendicular distance of the observation point from the wire.
- **Electric field due to uniformly charged thin spherical shell:**
  Electric field due to uniformly charged thin spherical shell or uniform surface charge density σ and radius R at a point distance r from the center of the shell is given as follows:
  - At a point outside the shell i.e., r > R
    $$E = \frac{1}{2\pi\varepsilon_0 r}\frac{q}{r^2}$$
  - At a point on the surface of the shell i.e., r = R

$E = \frac{1}{2\pi\varepsilon_0 r} \frac{q}{R^2}$

- At a point inside the shell i.e., r < R

  E=0

  Here, $q = 4\pi R^2 \sigma$

  The variation of E with r for a uniformly charged thin spherical shell is as shown in the figure.

- **Electric field due to a uniformly charged non-conducting solid sphere:** Electric field due to a uniformly charged non-conducting solid sphere of uniform volume charge density ρ and radius R at a point distant r from the center of the sphere is given as follows:
  - At a point outside the sphere i.e., r > R

    $E = \frac{1}{4\pi\varepsilon_0} \frac{q}{r^2}$
  - At a point on the surface of the sphere i.e., r = R

    $E = \frac{1}{4\pi\varepsilon_0} \frac{q}{R^2}$
  - At a point inside the sphere i.e., r < R

    $E = \frac{\rho r}{3\varepsilon_0} = \frac{1}{4\pi\varepsilon_0} \frac{qr}{R^3}$, for r < R

    Here,

    The variation of E with r for a uniform charged non-conducting sphere is as shown in the figure.
- **Electric field due to uniformly charged infinite thin plane sheet:** Electric field due to an infinite thin plane sheet of uniformly charged surface density is:

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

  E is independent of r, distance of the point from sheet.
- **Electric field due to two thin infinite parallel sheets of equal and opposite charges:** Electric field due to two thin infinite parallel sheets of uniform surface density is given as follows:
  - At a point anywhere in the space between the two sheets

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

- At point outside the sheets, E = 0.

Points to remember:

- Charge is the property associated with matter due to which it produces and experiences electrical and magnetic effects. The excess or deficiency of electrons in a body gives the concept of charge.
- Charge is a scalar quantity.
- Charge is transferable
- Charge is always associated with mass
- **Quantization of charge** : Total charge on a body is always an integral multiple of a basic unit of charge denoted by e and is given by q = ne, where n is any integer, positive or negative and e $=1.6\times10^{-19}C$
- The basic unit of charge is the charge that an electron or proton carries. By convention the charge on electron is -e($-1.6\times10^{-19}C$) and charge on proton is +e($1.6\times10^{-19}C$).
- **Additivity of charge:** Total charge of a system is the algebraic sum (i.e. Sum is taken into account with proper signs) of all individual charges in the system.
- **Conservation of charge:** Total charge of an isolated system remains unchanged with time.
- **The charge is invariant:** Charge is independent of the frame of reference.
- Like charges repel each other while unlike charges attract each other.
- Methods of charging include friction, induction and conduction.

Coulomb's law:

- It states that **"The electrostatic force of interaction (repulsion or attraction) between two electric charges q_1 and q_2 separated by a distance R is directly proportional to the product of the charges and inversely proportional to the square of the distance between them and act along the straight line joining two charges."**
- The ratio of Coulomb force to the gravitational force between two protons at a same distance apart is $\frac{e^2}{4\pi\varepsilon_0 G m_P m_p} = 1.3\times10^{36}$

- It states that, when a number of charges are interacting with each other, the total force on a given charge is vector sum of forces exerted on it by all other charges;
- The region surrounding a charge (or charge distribution) in which its electric effects are perceptible is called the electric field of the given charge.
- The types of charge distribution are linear and surface charge distribution.
- An electric field can be represented and so visualized by electric field lines.
- Electric field due to a positive point charge is represented by straight lines originating from the charge.
- The electric field due to a negative point charge is represented by straight lines terminating at the charge.
- Dipole is a pair of two equal and opposite charges separated by a small distance.
- Dipole moment is a vector quantity whose magnitude is equal to product of the magnitude of both charge and distance between the charges. i.e. $|\vec{p}| = q2a$
- The SI unit of electric dipole moment is C meter and its dimensional formula is $\left[M^0 LAT\right]$. The practical unit of electric dipole moment is debye.
- If the lines of force pass through a surface then the surface is set to have flux linked with it.
- **Gauss's Theorem:** The total flux linked with a closed surface is $\frac{1}{\varepsilon_0}$ times the charge enclosed by the closest surface (Gaussian surface) i.e., $\oint \vec{E}.d\vec{s} = \frac{q}{\varepsilon_0}$.

Important formulae:

- Quantization of charge: q=ne
- Coulomb's law: $F = K\frac{q_1 q_2}{r^2}$
- Coulomb's law in vector form: $\vec{F}_{21} = K\frac{q_1 q_2}{|\vec{r}_1 - \vec{r}_2|^3}(\vec{r}_1 - \vec{r}_2)$
- Superposition of charges:

$\vec{F} = Kq_0 \sum_{i=1}^{n} \frac{q_i \vec{r}_i}{r_i^2}$

- Electric field: $\vec{E} = \lim_{q_0 \to 0} \frac{\vec{F}}{q_0} = \frac{kq}{r^3}\vec{r}$
- Electric dipole: $|\vec{p}| = q2a$
- At the distance r from the center of the electric dipole, $E = \frac{1}{4\pi\varepsilon_0} \frac{2pr}{(r^2 - a^2)^2}$
- At the point at distance r from the center of electric dipole,

$E = \frac{1}{4\pi\varepsilon_0} \frac{qr}{\left(r^2 + a^2\right)^{3/2}}$

- The electric field intensity at point P due to an electric dipole, $E = \frac{1}{4\pi\varepsilon_0} \frac{p}{r^3} \sqrt{1 + 3\cos^2\theta}$
- Electric torque: $\vec{\tau} = \vec{p} \times \vec{E}$
- Gauss law: $\oint \vec{E}.d\vec{s} = \frac{q}{\varepsilon_0}$
- $E = \frac{\sigma}{2\varepsilon_0}$: Application of gauss law in an infinite plane sheet
- $E = \frac{1}{4\pi\varepsilon_0} \frac{q}{r^2}$: Electric field in a uniform thin wire

Questions:

1) The electric field at a distance $\frac{3R}{2}$ from the centre of a charged conducting shell of radius R is E. The electric field at distance $\frac{R}{2}$ is:

a) Zero b) E c) $\frac{E}{2}$ d) 3E

Answer: option a) zero

Solution:

WKT: Electric field is given by: $\vec{E} = \lim_{q_0 \to 0} \frac{\vec{F}}{q_0} = \frac{kq}{r^3}\vec{r}$

Here, inside a charged conductor electric field is always zero. So that the electric field between two plates had been reduced.
Therefore, electric field is zero.

2) An electric dipole is placed at an angle 30 degrees with electric field intensity 2×10^{5}NC. It experiences a torque equal to 4Nm. The charge on the dipole if length of the dipole is?

(a) 8mC
(b) 2mC
(c) 19mC
(d) 10mC

Answer: option b) 2mC

Solution:

$\theta = 30^{\circ}, E = 2\times10^{5} NC$

$\tau = 4Nm, l = 2cm = 0.02m$

q = ?

Electric torque is defined as: When an electric dipole of dipole moment $\vec{p}$ is placed in a uniform electric field $\vec{E}$, it will experience a torque and it is given by

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

$\tau = pE\sin\theta$

where θ is the angle between p and E.

WKT, $\tau = pE\sin\theta$

$$q = \frac{\tau}{E\sin\theta}$$

$$= \frac{4}{2\times10^{5}\times0.02\times0.5}$$

$$= 2\times10^{-3} = 2mC$$

Therefore, the electric field is 2mC.