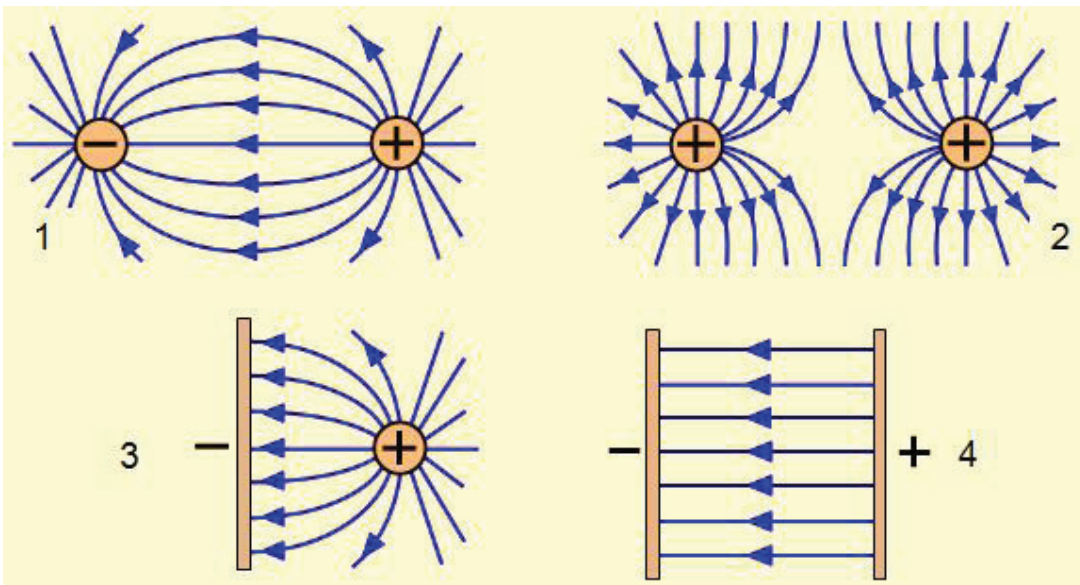
ELECTRIC CHARGES AND FIELDS



For Quick Revision and Smart Practice

NEET

FAST FORWARD

An Innovation of **NEET Experts** with **30+ years** of Blissful Teaching Experience and Inspiration of **Lakh+ successful MEDICO professionals**

India's First e - Magazine with Live Testing

Electric Charges and Fields

Charge and its properties

- Charge, like mass is a basic property of matter.
- Charges are of two types – the one on proton, by convention is named positive and the other an electron, by convention is named negative. A neutron has no net charge and is electrically neutral.

Fundamental properties of charges

(a) Charge is conserved – quantity the net of charge in an isolated system remains constant.

(b) Charge is quantized – the charge on any particle is an integral multiple of a fundamental unit of charge e, namely the charge on an electron or proton. $Q = \pm ne$: n = 1, 2, 3 … where $e = 1.6\times10^{-19}C$. Protons and neutrons are made up of quarks with fractional values of e. However, quarks do not occur in free state.

(c) Charge is invariant – unlike mass, length and time, charge on a body is independent of its state of motion (reference frames).

(d) Charge is a scalar and is additive.

(e) Like charges repel and unlike charges attract.

Auxillary properties of electric charge

(i) An electric charge in motion produces a magnetic field in addition to the electric field.

(ii) An accelerated charge radiates energy in the form of electromagnetic waves.

Methods of charging a body

Bodies can be charged by

- **Friction** (E.g. rubbing of glass with wool etc.)
  The two bodies acquire opposite kind of charge, due to one body losing electrons to other body.
- **Conduction** (E.g. bringing an uncharged body in contact with a charged body)
  During conduction, the body getting charged acquires part of the charge from the source (charging body).
- **Induction** (E.g. bringing a uncharged body near a charged body)
  During induction, the body getting charged acquires opposite kind of charge on its surface close to the charging body. The net charge on the charged body is still zero. However, by earthing, the charged body can be made to retain one type of charge. The charge on the source body remains intact. This method is applicable to only conductors.
- irradiating a conducting body by suitable electromagnetic radiation
- heating a body to a high temperature
- by applying a large electric field
- In all the above methods the body regains electrical neutrality over a period of time.
- Whether a body is charged or not and if charged, the type and extent of charge can be detected by a device called electroscope. The amount of charge on a body can be measured by a device called electrometer.

Coulomb's law: The force (F) of attraction or repulsion between two point charges is directly proportional to the product of the charges (Q_1 and Q_2) and inversely proportional to the square of the distance (r) between them.

$$F \propto \frac{Q_1Q_2}{r^2} \quad \therefore\ F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}$$

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

ε_0 is called the permittivity of free space and $\varepsilon_0 = 8.854 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$

Dimensional formula of permittivity is $M^{-1}L^{-3}T^{4}A^{2}$.

ε_r is greater than one for a medium other than vacuum. For air $\varepsilon_r \approx 1$. ε_r is called dielectric constant and is denoted by *K*.

Coulomb's law is strictly valid for point charges in vacuum. The presence of a medium modifies the force which is approximately given by $F = \frac{1}{4\pi\varepsilon_0\varepsilon_r}\frac{Q_1Q_2}{r^2}$

where ε_r is called the permittivity of the medium.

Coulomb's law in vector form

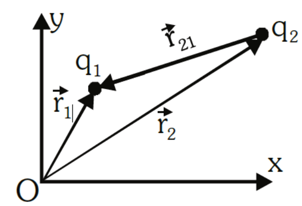
Coulomb's law of force between two point charges q_1 and q_2 located at $\vec{r}_1$ and $\vec{r}_2$ is written as

$\vec{F}_{21} = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r_{21}^2}\hat{r}_{21}$ where F_{21} is the force exerted on q_2 by q_1 and $\hat{r}_{21}$ is the unit vector towards q_2 from q_1 and $\vec{r}_{21} = \vec{r}_2 - \vec{r}_1$

Similarly force exerted on q_1 by q_2 is

$$\vec{F}_{12} = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r_{12}^2}\hat{r}_{12}$$

$\vec{r}_{12} = \vec{r}_1 - \vec{r}_2$ and $\hat{r}_{12}$ is the unit vector towards q_1 from q_2.



Coulomb's law in vector form

Since, the above equations are in vector form, q_1 and q_2 should be used with appropriate signs.

☞

- Coulomb's law is strictly applicable to point charges. However, in practice, charges are always associated with matter, which occupy finite volume. To simplify the situation, usually a charge is replaced by a charge of equal magnitude imagined to be concentrated at a single point. Such a charge is called a point charge.
- The gravitational force is usually neglected while studying the force between electric charges because gravitational force is negligible compared to electrostatic force. The ratio of electrostatic force of repulsion to the gravitational force of attraction between two electrons separated by 1 m is about 1.7×10^{43}.
- The relative permittivity ε_r of a medium is nearly constant. ε_r depends both on the property of the medium and the magnitude of the charges.
- ε_r is only a number and has no units. ε_r is also called dielectric constant.
- The unit of charge is coulomb (C).
- The charge on an electron is equal to -1.6×10^{-19} C.
- One coulomb charge has 6.25×10^{18} electrons.
- A test charge is a hypothetical infinitesimally small charge, kept at a point to evaluate the electric field at that point without disturbing the field.

Electric Field

The electric field at a point is defined as the force experienced per unit positive test charge (q_0) placed at that point. i.e.,

$$E = \frac{F}{q_0}$$

Electric field is measured in newton per coulomb (NC^{-1}). Its direction is always from a positive charge and towards a negative charge.

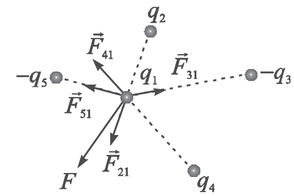
Electric field (E) at distance r from a point charge Q is $E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$

E is a vector and the resultant electric field at a point due to several charges is equal to the vector sum of the fields due to the individual charges.

Principle of superposition of electric forces

The resultant electric force at a point is the vector sum of the forces due to various charges. That is, $\vec{F}_{res} = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} + \ldots$

This is known as the principle of superposition of electric forces.



Superposition of electric forces

Electric dipole

Two equal and opposite charges separated by a small distance are said to form an electric dipole.

Every dipole is associated with a dipole moment $\vec{p}$ whose magnitude is equal to the product of the magnitude of any one charge (q) and the distance $(2a)$ between them. $\vec{p} = q \times 2\vec{a}$.

The direction of $\vec{p}$ is from negative charge to positive charge. Its unit is coulomb metre.

Field at a point on the axial line of electric dipole

$$\vec{E} = \frac{\vec{p}}{4\pi\varepsilon_0}\frac{2r}{(r^2 - a^2)^2}$$

For a point on the axis far away from the centre of the dipole (meaning a short dipole).

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{2\vec{p}}{r^3}$$

The direction of $\vec{E}$ is along the direction of dipole moment.

Field at a point on the equatorial line of dipole

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

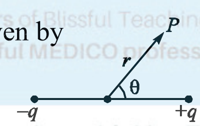
For a point on the equatorial line of a short dipole, $\vec{E} = \frac{1}{4\pi\varepsilon_0}\left(-\frac{\vec{p}}{r^3}\right)$

The direction of $\vec{E}$ is antiparallel to the direction of electric dipole moment.

Field at any point due to a dipole

At an arbitrary point P, electric field due to a short dipole is given by

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



Torque on dipole in an electric field

When an electric dipole of moment $\vec{p}$ is held at an angle θ with the direction of *a* uniform electric field $\vec{E}$, a torque acts on the dipole, which is given by $\vec{\tau} = \vec{p} \times \vec{E} = pE\sin\theta$ in magnitude.

The torque tries to align the dipole in the direction of the field.

Electric field due to a continuous distribution of charge

If a charge Q is distributed uniformly over a body, then the electric field at a point P distant r from an element with charge dQ in the body is given by $dE = \frac{1}{4\pi\varepsilon_0}\frac{dQ}{r^2}$.

The field due to the entire body is given by $E = \frac{1}{4\pi\varepsilon_0}\int\frac{dQ}{r^2}$

(a) For linear distribution of charge, dQ = λdl, where λ is called the linear charge density.

(b) For surface distribution of charge, dQ = σds, where σ is called surface charge density

(c) For volume distribution of charge dQ = ρdV where ρ is called volume charge density.