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NCERT CHAPTER 1

Electric Charges and Fields

1. Every substance is made up of atoms which in turn contain electrons, protons and neutrons. Atoms on the whole are electrically neutral. Charges appear on bodies when some electrons are transferred from one object to another.
2. There are two types of electric charge; positive and negative. A body acquires negative charge when it gains electrons. The charge acquired by a body is positive when it loses electrons.
3. When a glass rod is rubbed with silk; some electrons are transferred from glass rod to silk. Silk acquires negative charge leaving an equal positive charge on glass rod. Charges developed on the bodies are always equal and opposite.
4. Like charges or similar charges repel each other whereas unlike/dissimilar charges attract each other.
5. Electric charge can be produced on a body by (*i*) friction (*ii*) conduction or (*iii*) induction.
6. Electric charge is a scalar quantity and is additive in nature *i.e.,* total charge on a body is equal to the algebraic sum of individual charges given to it.

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7. Electric charge is quantised in nature *i.e.,* it can exist only as an integral multiple of charge on electron or proton *i.e.,* 1.6×10^{-19} C. Mathematically, charge $q = \pm n e$ where n is a whole number. The smallest charge which can exist independently is e (= 1.6×10^{-19} C).
8. Electric charge can neither be created nor destroyed. It can only be transferred from one object to another. The total electric charge on an isolated system always remains constant. This is called the law of conservation of charge.
9. The force between charges is given by Coulomb's law. For two point charges, the force is directly proportional to the product of the charges and inversely proportional to the square of the distance between them.

   Mathematically,

$$\vec{F} = \frac{1}{4\pi \in_0} \frac{q_1 q_2}{r^2} \cdot \hat{r} = 9 \times 10^9 \frac{q_1 q_2}{r^2} \hat{r} \text{ N in vacuum}$$

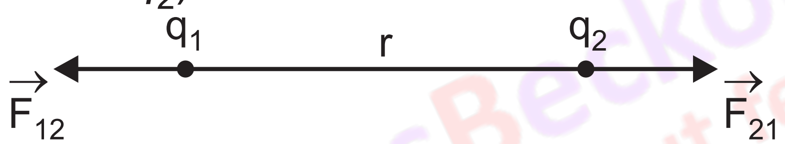
and $F_{medium} = \frac{1}{4\pi \in_0 K} \frac{q_1 q_2}{r^2} = \frac{1}{4\pi \in_0 \in_r} \frac{q_1 q_2}{r^2} = \frac{F_{vac}}{K}$

in a medium

where K is dielectric constant of the medium.

10. ϵ_0 is called electrical permittivity of free space and is $8.854 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$ and $\frac{1}{4\pi \epsilon_0} = 9 \times 10^9\ Nm^2\ C^{-2}$.

11. Coulomb's law is compatible with Newton's third law of motion *i.e.*, force on q_2 due to q_1 = $\overrightarrow{F_{21}} = -\overrightarrow{F_{12}}$ (– of force on q_1 due to q_2)



12. The SI unit of electric charge is coulomb. 1C is the charge which exerts a force of 9×10^9 N on an equal and similar point charge placed 1m away in vacuum.

13. The force of attraction or repulsion between two charges is not affected by presence of any other charge or system of charges.

14. The net force on a charge due to a system of other charges is the vector sum of the force on the charge due to all other individual charges. For a system of charges q_1; q_2; q_3, ... q_n; the net force on q_1 is

$$\vec{F_1} = \overrightarrow{F_{12}} + \overrightarrow{F_{13}} + \overrightarrow{F_{14}} + \ldots = \frac{q_1}{4\pi \epsilon_0} \sum_{i=2}^{n} \frac{q_i}{r_{1i}^2} \hat{r}_{1i}.$$

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and the net force on q_i is given by

$$\vec{F}_i = \frac{1}{4\pi \epsilon_0} \sum_{\substack{j=1 \\ j \neq i}}^{n} \left(\frac{q_i\, q_j}{r_{ij}^2} \right) \hat{r}_{ij}$$

15. Electric field intensity $\vec{E}$ at a point due to a charge configuration is the force acting on a unit positive charge placed at that point. Mathematically, $\vec{E} = \lim_{q_0 \to 0} \frac{\vec{F}}{q_0}$ where $\vec{F}$ is the force on a small positive test charge q_0 placed at that point.

Mathematically, the electric field intensity $\vec{E}(r)$ at a point with position vector $\vec{r}$ (due to a charge q at origin) is given by

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$$\vec{E}(r) = \underset{q_0 \to 0}{Lt} \frac{\vec{F}}{q_0} = \frac{q}{4\pi \in_0 r^2}\hat{r} = \frac{q}{4\pi \in_0} \frac{\vec{r}}{r^3}.$$

The field is directed away from positive charge and towards negative charge. The field due to a point charge is spherically symmetric.

16. The electric field intensity is a vector in the direction of the force on the positive test charge. Its SI unit is NC^{-1} or Vm^{-1}.

17. The net electric field at a point due to a number of charges is the vector sum of the electric fields due to the various individual charges *i.e.,* the electric field intensity follows superposition principle.

Thus $\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + ...$

18. An electric field line is a smooth curve in an electric field such that a tangent drawn at any point on the curve gives the direction of electric field at that point.

19. The electric field lines start from positive charge and terminate on negative charge. They are continuous but do not form closed loops. The field lines never intersect each other and cannot pass through the body of a conductor. The field lines are closely packed in the stronger parts of the field.

20. The number of electric field lines passing per unit area of a surface held normal to the direction of the electric field measures the intensity of the field. Hence the field lines are far apart in weaker region of electric field and crowded in the stronger parts of the field. The field lines in a uniform electric field are equally spaced parallel lines.

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21. A pair of equal and opposite charges (+*q* and –*q*) placed at certain small distance (say 2*a*) apart is called an electric dipole.

22. The product of either of the charges and the distance between them is called electric dipole moment. Mathematically, $\vec{p} = q \, . \, \overrightarrow{2a}$. It is a vector directed from –ve to +ve charge. Its SI unit is Cm.

23. The electric field intensity due to a dipole at a point situated at a distance *r* from its centre on the axial line of the dipole is given by

$$\vec{E} = \frac{1}{4\pi \epsilon_0} \frac{2\vec{p}.r}{(r^2 - a^2)^2}$$

$$= \frac{1}{4\pi \epsilon_0} \frac{2\vec{p}}{r^3}$$ for $r >> a$; *i.e.*, for a far off point and a short dipole.

The electric field acts in the direction of the electric dipole moment.

24. The electric field intensity due to a dipole at a point situated at a distance *r* from centre on the equatorial line of the dipole is given by

$$\vec{E} = -\frac{1}{4\pi \epsilon_0} \frac{\vec{p}}{\left(r^2 + a^2\right)^{3/2}}$$

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For a short dipole or for $r >> a$;

$$\vec{E} = -\frac{1}{4\pi \in_0} \frac{\vec{p}}{r^3}.$$

The electric field acts in a direction opposite to that of the electric dipole moment.

25. The net force acting on an electric dipole placed in a uniform electric field is zero. The dipole however experiences a torque τ given by

$$\vec{\tau} = \vec{p} \times \vec{E} \quad \text{or} \quad \tau = pE \sin \theta.$$

The direction of the torque is given by right hand rule applied to $\vec{p} \times \vec{E}$. So $\vec{\tau} \perp \vec{p}$; $\vec{\tau} \perp \vec{E}$.

The torque is maximum when dipole is held normal to the field direction (*i.e.,* θ = 90°) and is zero when it is held parallel or anti parallel (*i.e.,* θ = 0° or 180°) to the field.

26. The electrostatic potential of an electric dipole in a uniform electric field is given by $U = -\vec{p} \cdot \vec{E} = -pE \cos \theta$.

The energy is zero when $\theta = 90° \left(\vec{p} \perp \vec{E}\right)$;

maximum when $\theta = 180°$ (Dipole anti parallel to field)

and minimum when $\theta = 0°$ (Dipole parallel to the field)

$$U_{max} = pE; \quad U_{min} = -pE.$$

Hence the torque on the dipole tends to align the dipole in the direction of the electric field.

27. An electric dipole placed in a non-uniform electric field experiences both a force as well as a torque.

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28. For a continuous charge distribution over a linear object the electric field intensity at a point *P* is given by

$$\vec{E} = \frac{1}{4\pi \epsilon_0} \int \frac{\lambda dl}{r^2} \hat{r}$$ where $\lambda = \frac{\text{charge}}{\text{length}}$ (Cm^{-1}) at a distance *r* from the point *P*

29. For a continuous charge distribution over a surface, the electric field intensity at a point *P* is given by

$$\vec{E} = \frac{1}{4\pi \epsilon_0} \int \frac{\sigma ds}{r^2} \hat{r}$$ where $\sigma = \frac{\text{charge}}{\text{area}}$ (Cm^{-2}) (or surface charge density)

30. For a continuous charge distribution over a volume; the electric field intensity at a point *P* is given by

$$\vec{E} = \frac{1}{4\pi \epsilon_0} \int \frac{\rho dv}{r^2} \hat{r}$$ where $\rho = \frac{\text{Charge}}{\text{Volume}}$ (Cm^{-3}) (or volume charge density)

31. An electric field changing with time produces magnetic field and vice-versa. These time varying fields, as we will study later, travel simultaneously in electromagnetic waves.

32. Electric flux ϕ_E passing through an area $\vec{S}$ in an electric field $\vec{E}$ is given by

$$\phi_E = \vec{E}.\vec{S} = ES \cos \theta \quad \text{if field is uniform}$$

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$$\phi_E = \int_s \vec{E}.\vec{ds} = \int_s \vec{E}.\hat{n}\, ds = \int_s E ds \cos\theta \quad \text{if}$$

field is non-uniform

where θ is angle between $\vec{E}$ and normal to the surface.
The electric flux is a scalar. Its SI unit is $Nm^2\ C^{-1}$ or V-m
The flux may be positive, negative or zero.

33. Electric flux linked with a surface is a measure of the total number of electric field lines passing normally through that surface.

34. Gauss law in electrostatics states that the total electric flux over a closed surface in free space is $\frac{1}{\epsilon_0}$ times the net charge enclosed within that surface.

Mathematically, $\phi_E = \oint_s \vec{E}.\hat{n}\, ds = \frac{1}{\epsilon_0}(Q)$ where Q is the total charge inside S.

35. Total electric flux over any closed surface enclosing an electric dipole is zero.

36. Gauss theorem can be applied to determine electric field intensity due to some symmetric charge distribution.

37. The electric field intensity at a point P at a normal distance r from a long thin conductor with uniform linear charge density λ is given by

$$\vec{E} = \frac{\lambda}{2\pi \epsilon_0 r}\hat{n} \Rightarrow E \propto \frac{1}{r} \text{ and } E \propto \lambda.$$

38. The electric field intensity at a point P due to a large flat (thin plane) sheet is

$$\vec{E} = \frac{\sigma}{2\epsilon_0}\hat{n}$$ where σ is the surface density of electric charge.

39. The electric field intensity at a point P due to a thin uniformly charged shell is given by

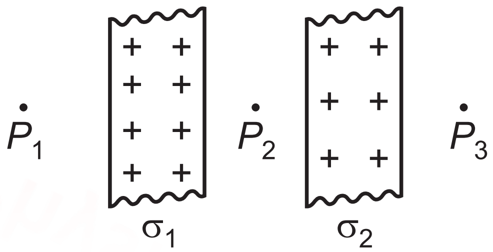
$$\vec{E} = 0 \quad \text{for} \quad r < R$$

$$= \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}\hat{r} \quad \text{for} \quad r \geq R$$

where r is distance of point P from the centre O of the charged shell of radius R. For points outside the shell, the field of the shell behaves as if it is concentrated at the centre of the shell.

40. For a pair of large flat parallel thin plates with uniform charge densities σ_1 and σ_2; $(\sigma_1 > \sigma_2 > 0)$;

$$E_{P_1} = -\left(\frac{\sigma_1 + \sigma_2}{2\epsilon_0}\right); \; E_{P_2} = \left(\frac{\sigma_1 - \sigma_2}{2\epsilon_0}\right) \text{ and } E_{P_3} = \left(\frac{\sigma_1 + \sigma_2}{2\epsilon_0}\right)$$



Negative sign indicates electric field intensity towards left or negative X-direction.

If $\sigma_1 = -\sigma_2 = \sigma$; then $E_{P_1} = E_{P_3} = 0$ and $E_{P_2} = \frac{\sigma}{\epsilon_0}$.