

Electric Field

Electric Field Intensity (E) = $\lim_{q \rightarrow 0} \frac{F}{q}$
Force experienced by the test charge / Test charge
 SI unit: NC^{-1} or VM^{-1} (NLT/A)

Due to Point charge

$$E = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2}$$

Due to System of Charges (superposition principle)

$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \dots$$

$$E = \frac{1}{4\pi\epsilon_0} \sum \frac{q_i}{r_i^2}$$

Due to Continuous Charge Distribution

- Linear charge distribution

$$E = \frac{1}{4\pi\epsilon_0} \int \frac{\lambda}{r^2} dl$$

- Surface charge distribution

$$E = \frac{1}{4\pi\epsilon_0} \int \frac{\sigma}{r^2} dS$$

- Surface charge distribution

$$E = \frac{1}{4\pi\epsilon_0} \int \frac{\rho}{r^2} dV$$

At a point on the axis of uniformly charged ring

$$E = \frac{1}{4\pi\epsilon_0} \frac{qx}{(x^2 + R^2)^{3/2}}$$



Electric dipole:

$\vec{p} = q \cdot 2a$
Electric dipole moment / Vector quantity

At a point on Axial line of dipole:



If $x \gg 2a$, then $E = \frac{1}{4\pi\epsilon_0} \frac{2p}{x^3}$

$$E = \frac{1}{4\pi\epsilon_0} \frac{2px}{(x^2 - a^2)^2}$$

At a point on equatorial line of dipole:



$$E = \frac{1}{4\pi\epsilon_0} \frac{p}{(x^2 + a^2)^{3/2}}$$

If $x \gg 2a$, then $E = \frac{1}{4\pi\epsilon_0} \frac{p}{x^3}$

Electric flux (ϕ): Electric flux over an area is equal to the total number of electric field lines crossing this area.

$$\phi = \int \vec{E} \cdot d\vec{S} = \int E dS \cos\theta$$

Applications of Gauss' Theorem

Due to an infinite Line charge

$$E = \frac{1}{4\pi\epsilon_0} \frac{2\lambda}{r} \Rightarrow E = \frac{\lambda}{2\pi\epsilon_0 r}$$

Near an infinite Plane Sheet of charge

$$E = \frac{\sigma}{2\epsilon_0}$$



For thick charged sheet, $E = \frac{\sigma}{\epsilon_0}$

Due to uniformly charged spherical shell (Gaussian sphere)

(a) Outside the shell $E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$

(b) At the surface of a shell $E = \frac{1}{4\pi\epsilon_0} \frac{Q}{R^2}$

(c) Inside the shell $E = 0$



Due to uniformly charged non-conducting solid sphere

(a) Outside the sphere $E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$

(b) At the surface of a sphere $E = \frac{1}{4\pi\epsilon_0} \frac{Q}{R^2}$

(c) Inside the sphere $E = \frac{1}{4\pi\epsilon_0} \frac{Qr}{R^3}$



Gauss' Theorem:

$$\phi = \oint E dS = \frac{1}{\epsilon_0} \cdot q_{enc}$$

- If a charge q is placed at the center of cube, then total flux linked with the whole cube is ϕ & electric flux linked with one face of cube is $\phi/6$
- If a charge q is placed on one corner of cube, then total flux linked with the whole cube is $\phi/8$

At any point along a line making θ angle with dipole axis:

$$E = \frac{1}{4\pi\epsilon_0} \frac{p \sqrt{1 + 3 \cos^2 \theta}}{r^3}$$

Due to two infinite parallel sheets of charge:



Torque on dipole in uniform electric field

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

- If $\theta = 0^\circ$ - Stable equilibrium
- If $\theta = 180^\circ$ - Unstable equilibrium

Work done in Potential Energy of dipole in uniform Electric Field:

$$W = -pE (\cos\alpha - \cos\beta) \quad W = pE (1 - \cos\theta)$$

If dipole is rotated by an angle $\theta = 180^\circ$ to $\theta = 0^\circ$, then Potential energy

$$W = U = -pE \cos\theta = -pE$$

Conceptual Physics Electric Field And Potential

PT Brinkman



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