ELECTRIC FIELD

In order to explain the interaction of bodies which are in out of contact, the early scientists introduced the concept of field. According to this, we say that the charge Q produces an electric field everywhere in the surrounding.

When another charge q is brought at some point P, the field there acts on it and produces a force. The electric field produced by the charge Q at a point r is given as

$$\mathbf{E}(\mathbf{r}) = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}\hat{\mathbf{r}} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}\hat{\mathbf{r}}$$

where $\hat{\mathbf{r}} = \mathbf{r}/r$, is a unit vector from the origin to the point $\mathbf{r}$.

If we denote the position of charge q by the vector r, it experiences a force F equal to the charge q multiplied by the electric field E at the location of q. Thus,

$$\mathbf{F}(\mathbf{r}) = q\,\mathbf{E}(\mathbf{r})$$

Thus, the **electric field** due to a charge Q at a point in space may be defined as the force that a unit positive charge would experience if placed at that point.

The charge Q, which is producing the electric field, is called a **source** charge and the charge q, which tests the effect of a source charge, is called a **test** charge.

Test charge must be infinitesimally small

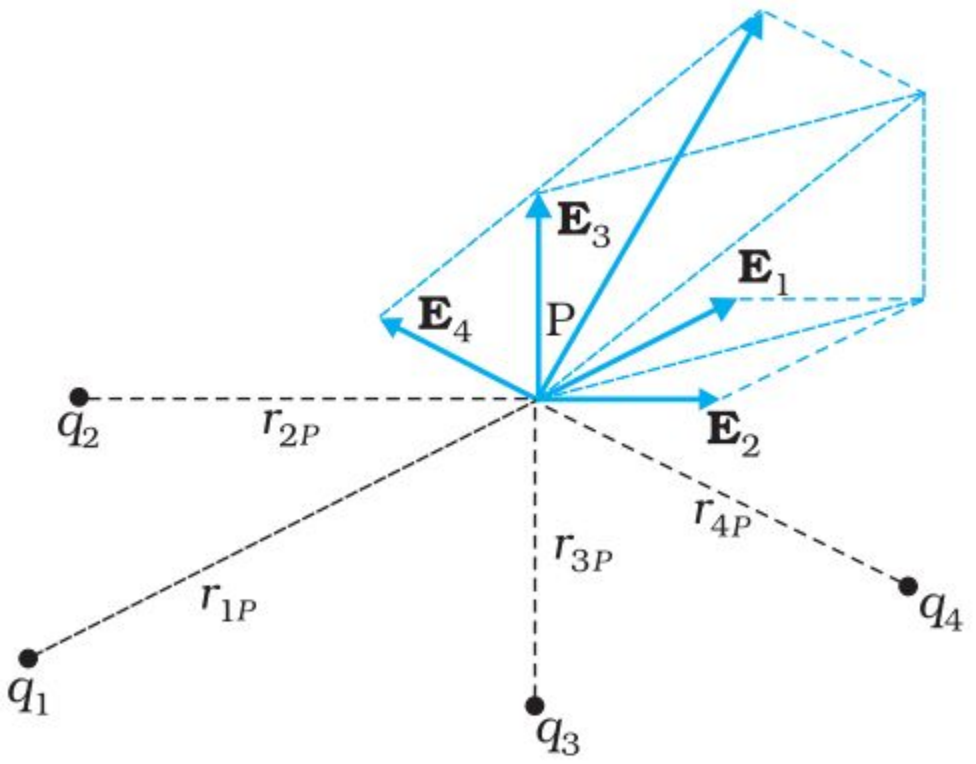
However, if a charge q is brought at any point around Q, Q itself is bound to experience an electrical force due to q and will tend to move. A way out of this difficulty is to make q negligibly small.

$$\mathbf{E} = \lim_{q \to 0} \left(\frac{\mathbf{F}}{q} \right)$$

Note that the electric field E due to Q, and is independent of q. This is because F is proportional to q, so the ratio F/q does not depend on q.

For a positive charge, the electric field will be directed radially outwards from the charge. On the other hand, if the source charge is negative, the electric field vector, at each point, points radially inwards.

Electric field due to a system of charges



Superposition Principle

$$\mathbf{E}(\mathbf{r}) = \mathbf{E}_1(\mathbf{r}) + \mathbf{E}_2(\mathbf{r}) + \ldots + \mathbf{E}_n(\mathbf{r})$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{q_1}{r_{1P}^2}\hat{\mathbf{r}}_{1P} + \frac{1}{4\pi\varepsilon_0}\frac{q_2}{r_{2P}^2}\hat{\mathbf{r}}_{2P} + \ldots + \frac{1}{4\pi\varepsilon_0}\frac{q_n}{r_{nP}^2}\hat{\mathbf{r}}_{nP}$$

$$\mathbf{E}(\mathbf{r}) = \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{n}\frac{q_i}{r_{iP}^2}\hat{\mathbf{r}}_{iP}$$

Physical significance of electric field

The term field in physics generally refers to a quantity that is defined at every point in space and may vary from point to point. Electric field is a vector field, since force is a vector quantity

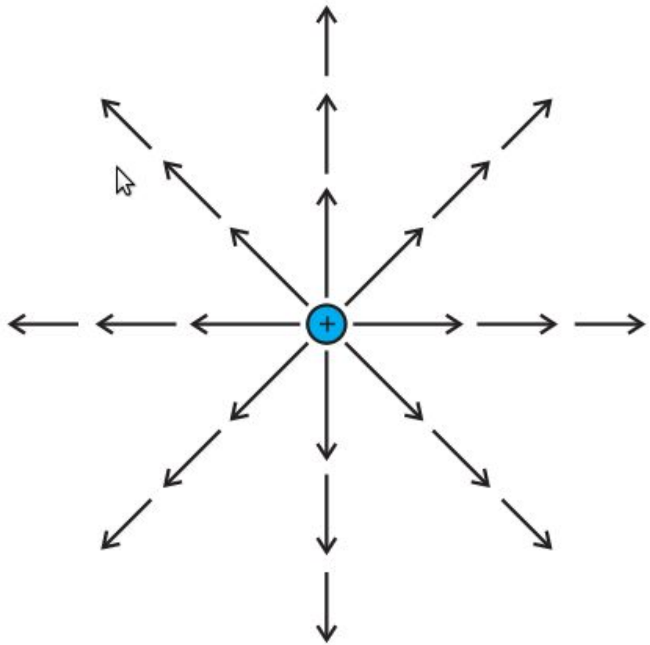
The true physical significance of the concept of electric field, however, emerges only when we go beyond electrostatics and deal with time-dependent electromagnetic phenomena

The field picture is this: the **accelerated** motion of charge $\mathbf{q_1}$ produces **electromagnetic waves**, which then **propagate** with the **speed c**, reach $\mathbf{q_2}$ and cause a force on $\mathbf{q_2}$

Electric field acts as intermediary in the interaction between two charges.

The first charge sets up an electric field around it, and the second charge interacts with the electric field of the first charge.

ELECTRIC FIELD LINES



Field lines carry information about the **direction** of electric field at **different** points in space

The **magnitude** of the field is represented by the **density** of field lines. E is strong near the charge

The direction of the electric field is everywhere tangent to the field-lines, in the sense of the arrows on the lines. The magnitude of the field is proportional to the number of field-lines per unit area passing through a small surface normal to the lines.

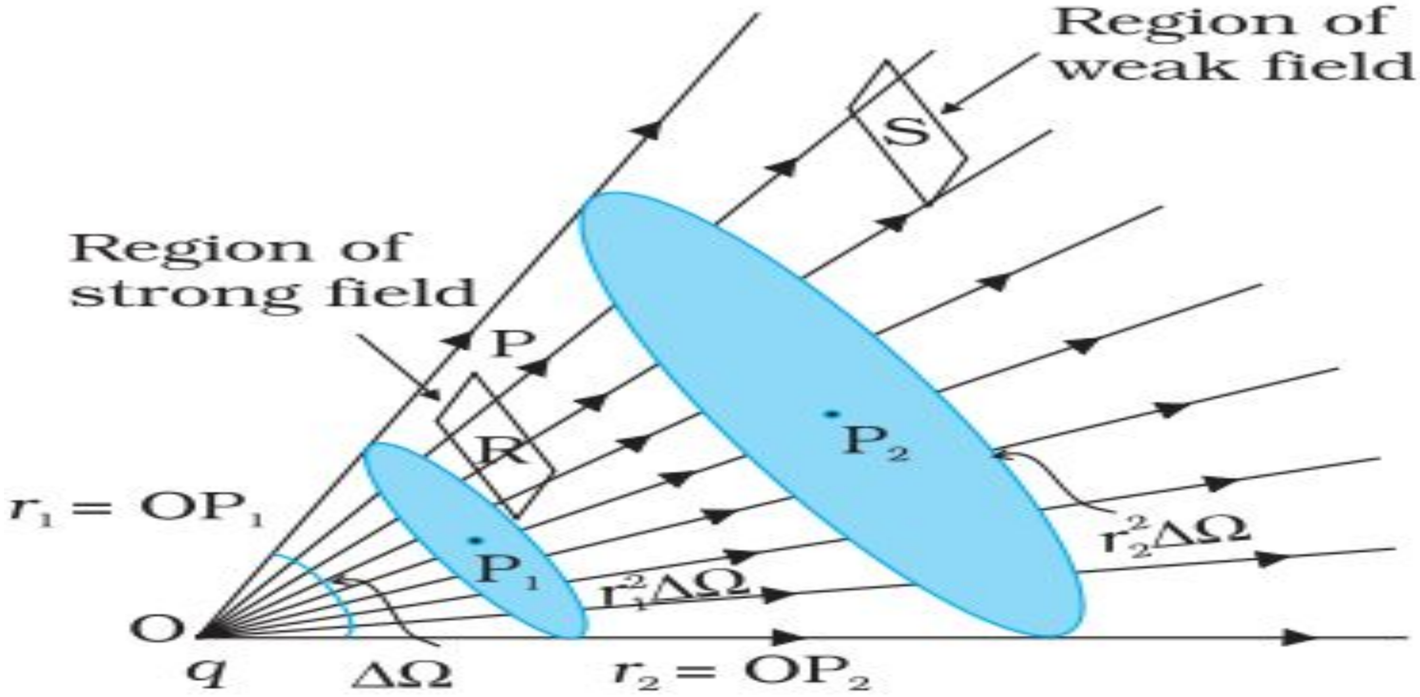


FIGURE 1.16 Dependence of electric field strength on the distance and its relation to the number of field lines.

Characteristics of Lines of force

1. The electric lines of force are imaginary lines.
2. A unit positive charge placed in the electric field tends to follow a path along the field line if it is free to do so.
3. The electric lines of force emanate from a positive charge and terminate on a negative charge.

4. Two electric lines of force can never cross each other. If they do, then at the point of intersection, there will be two tangents. It means there are two values of the electric field at that point, which is not possible. Further, electric field being a vector quantity, there can be only one resultant field at the given point, represented by one tangent at the given point for the given line of force.

4. The tangent to an electric field line at any point gives the direction of the electric field at that point.

6. Electric lines of force are closer (crowded) where the electric field is stronger and the lines spread out where the electric field is weaker.

7. Electric lines of force are perpendicular to the surface of a positively or negatively charged body.

8. Electric lines of force contract lengthwise to represent attraction between two unlike charges.

9. Electric lines of force exert lateral (sideways) pressure to represent repulsion between two like charges.

10. Electric lines of force do not pass through a conductor. Hence, the interior of the conductor is free from the influence of the electric field.

11. Electric lines of force can pass through an insulator.

ELECTRIC FLUX

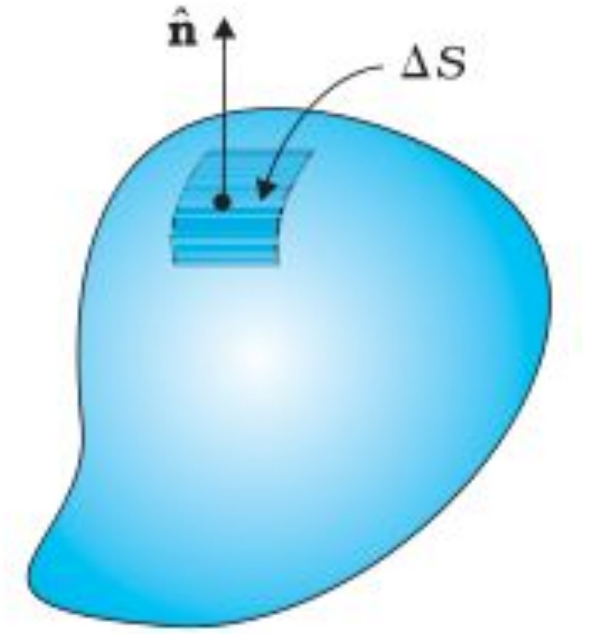
Electric flux is the total number of lines of force passing through a surface

In physical sense,**electric flux** is **defined** as: "The total number of lines of force passing through the unit area of a surface held perpendicularly

Electric flux for a small element

Electric flux Δφ through an area element ΔS is defined by

$\Delta\varphi = E.\Delta S = E\ \Delta S \cos\theta$



To calculate the total flux through any given surface. All we have to do is to divide the surface into small area elements, calculate the flux at each element and add them up. Thus, the total flux φ through a surface S is

$$\varphi \sim \Sigma\, E.\Delta S$$

Electric Flux is the Surface integral of the electric field over the whole surface

$$\Phi_E = \mathbf{E} \cdot \mathbf{S} = ES\cos\theta,$$

$$d\Phi_E = \mathbf{E} \cdot d\mathbf{S}$$

$$\Phi_E = \iint_S \mathbf{E} \cdot d\mathbf{S}$$

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MAXIMUM FLUX

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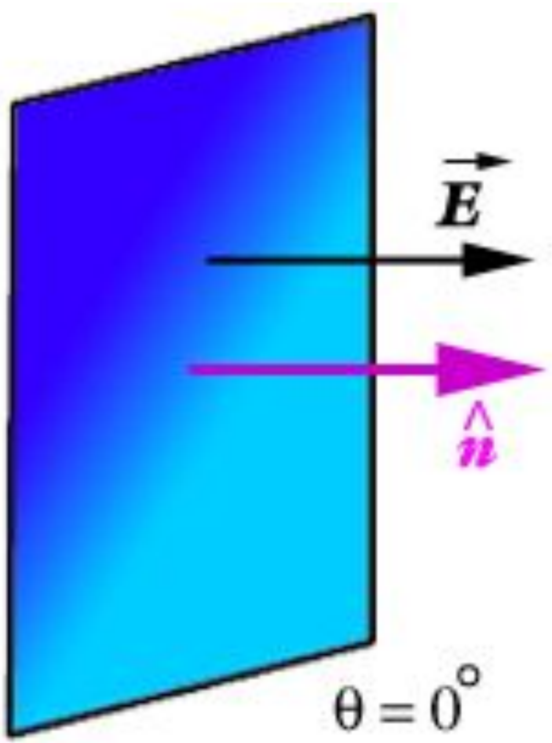

$$\phi_e = \vec{E} \cdot \vec{\Delta A}$$

$$\phi_e = E \ \Delta A \cos 0^\circ$$

$$\phi_e = E \ \Delta A \ (1)$$

$$\boxed{\phi_e = E \ \Delta A}$$

ZERO FLUX

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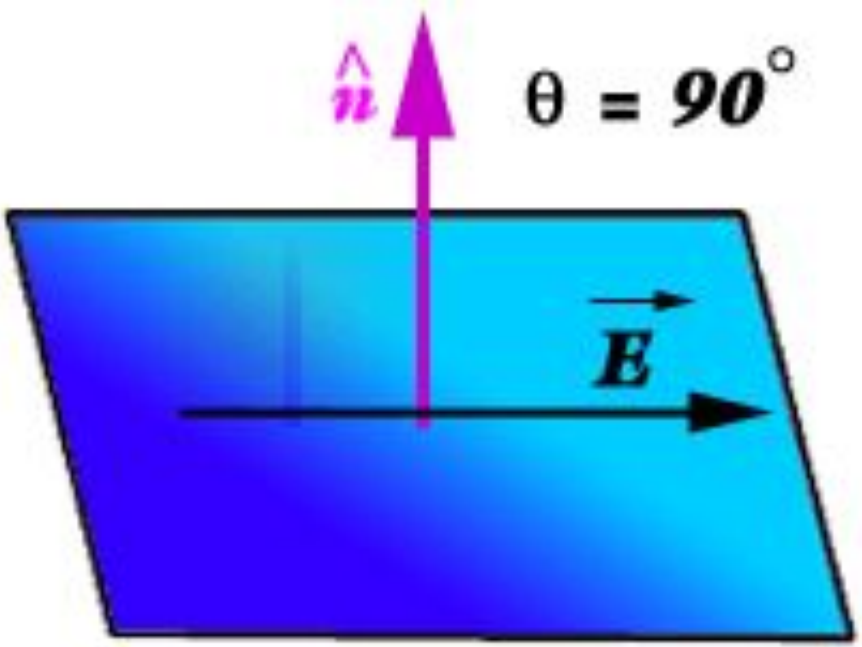

$$\phi_e = \vec{E} \, . \, \Delta\vec{A}$$

$$\phi_e = E \;\; \Delta A \cos 90^{\circ}$$

$$\phi_e = E \;\; \Delta A \; (0)$$

$$\boxed{\phi_e = 0}$$