

Electric field

Contributed by: Ralph P. Winch, A. E. Bailey, Ralph P. Winch

Publication year: 2014

A condition in space in the vicinity of an electrically charged body such that the forces due to the charge are detectable. An electric field (or electrostatic field) exists in a region if an electric charge at rest in the region experiences a force of electrical origin. Since an electric charge experiences a force if it is in the vicinity of a charged body, there is an electric field surrounding any charged body.

Field strength

The electric field intensity (or field strength) \mathbf{E} at a point in an electric field has a magnitude given by the quotient obtained when the force acting on a test charge q' placed at that point is divided by the magnitude of the test charge q' . Thus, it is force per unit charge. A test charge q' is one whose magnitude is small enough so it negligibly alters the field in which it is placed. The direction of \mathbf{E} at the point is the direction of the force \mathbf{F} on a positive test charge placed at the point. Thus, \mathbf{E} is a vector point function, since it has a definite magnitude and direction at every point in the field, and its defining equation is (1).

$$\mathbf{E} = \frac{\mathbf{F}}{q'} \quad (1)$$

Ralph P. Winch

Principle of superposition

The field at a distance of r meters from a point charge of q coulombs in vacuum is given by Eq. (2),

$$\mathbf{E} = \frac{q}{4\pi\epsilon_0 r^2} \quad (2)$$

where \mathbf{E} is the field strength in volts per meter and $\epsilon_0 = 8.85 \times 10^{-12}$ farad/meter is the permittivity of free space. \mathbf{E} is a vector, directed along the radius vector from the point charge; positive \mathbf{E} is directed away from a positive charge or toward a negative charge. For an assembly of charges, the resultant field is, by the principle of superposition, the vector sum of the field components due to the individual charges. This summation may be

performed directly, but in practical cases Gauss' theorem often affords a more powerful and convenient method.
See also: GAUSS' THEOREM.

A. E. Bailey

Electric displacement

Electric flux density or electric displacement \mathbf{D} in a dielectric (insulating) material is related to \mathbf{E} by either of the equivalent equations (3),

$$\mathbf{D} = \epsilon_0 \mathbf{E} + \mathbf{P} \quad \mathbf{D} = \epsilon \mathbf{E} \quad (3)$$

where \mathbf{P} is the polarization of the medium, and ϵ is the permittivity of the dielectric, which is related to ϵ_0 by the equation $\epsilon = \epsilon_r \epsilon_0$, ϵ_r being the relative permittivity of the dielectric. In empty space, $\mathbf{D} = \epsilon_0 \mathbf{E}$. The units of \mathbf{D} are coulombs per square meter. *See also:* PERMITTIVITY; POLARIZATION OF DIELECTRICS.

In addition to electrostatic fields produced by separations of electric charges, an electric field is also produced by a changing magnetic field. The relationship between the \mathbf{E} produced and the rate of change of magnetic flux density $d\mathbf{B}/dt$ which produces it is given by Faraday's law of induced electromotive forces (emfs) in Eq. (4),

$$\oint \mathbf{E} \cdot d\mathbf{s} = - \int_A \frac{d\mathbf{B}}{dt} \cdot d\mathbf{A} \quad (4)$$

where $d\mathbf{s}$ is a vector element of path length directed along the path of integration in the general sense of \mathbf{E} . Thus $\oint \mathbf{E} \cdot d\mathbf{s}$ is the emf induced in this closed path of integration. The area of the surface bounded by the path of integration is A , and the direction of $d\mathbf{A}$, an infinitesimal vector element of this area, is the direction of the thumb of the right hand when the fingers encircle the path of integration in the general sense of \mathbf{E} . The right side of Eq. (4) is seen to be the negative of the time rate of change of the magnetic flux linking the path of integration chosen for the left side.

In an electrostatic field, $\oint \mathbf{E} \cdot d\mathbf{s}$ is always zero. *See also:* ELECTRIC CHARGE; ELECTROMAGNETIC INDUCTION; POTENTIALS.

Ralph P. Winch

Bibliography

D. Halliday, R. Resnick, and J. Walker, *Fundamentals of Physics*, 9th ed., Wiley, 2011

E. M. Purcell and D. J. Morin, *Electricity and Magnetism*, 3d ed., Cambridge University Press, 2013

H. D. Young and R. A. Freedman, *Sears and Zemansky's University Physics*, 13th ed., Addison-Wesley, 2011