Quantum Mechanics_electric potential

In classical electromagnetism, the **electric potential** (a scalar quantity denoted by Φ, $Φ_E$ or *V*and also called the *electric field potential* or the*electrostatic potential*) at a point of space is the amount of Electric potential energy that a unitary point charge would have when located at that point. The electric potential of a point may also be defined as the work done in carrying a unit positive charge from infinity to that point.

The electric potential at a point is equal to theElectric potential energy (measured in joules) of any charged particle at that location divided by thecharge (measured in coulombs) of the particle. Since the charge of the test particle has been divided out, the electric potential is a "property" related only to the electric field itself and not the test particle. The electric potential can be calculated at a point in either a static (time-invariant) Electric field or in a dynamic (varying with time) Electric field at a specific time, and has the units of joules percoulomb ($J\ C^{-1}$), or volts (*V*).

There is also a generalized electric scalar potentialthat is used in electrodynamics when time-varying electromagnetic fields are present. This generalized electric potential cannot be simply interpreted as the ratio of potential energy to charge, however.

Introduction

Objects may possess a property known as an Electric charge. An Electric fieldexerts a force on charged objects. If the charged object has a positive charge, the force will be in the direction of the electric field vector at that point. The force will be in the opposite direction if the charge is negative. The magnitude of the force is given by the quantity of the charge multiplied by the magnitude of the electric field vector. A net force acting on an object will cause it to accelerate, as explained by Classical mechanics which explores concepts such as force, energy,potential etc. The electric potential (or simply potential) at a point in an electric field is defined as the work done in moving a unit positive charge from infinity to that point. The electric potential at infinity is assumed to be zero.

Force and potential energy are directly related. As an object moves in the direction that the force accelerates it, its potential energy decreases. For example, the gravitational potential energy of a cannonball at the top of a hill is greater than at the base of the

hill. As the object falls, that potential energy decreases and is translated to motion, or inertial (kinetic) energy.

For certain force fields, it is possible to define the "potential" of a field such that the potential energy of an object due to a field depends only on the position of the object with respect to the field. Those forces must affect objects depending only on the intrinsic properties of the object (e.g., mass or charge) and the position of the object, and obey certain other mathematical rules.

Two such force fields are the gravitational force field (gravity) and the electric field in the absence of time-varying magnetic fields. The potential of an electric field at a point is called the electric potential. The synonymous term "electrostatic potential" is also in common use.

The electric potential and the magnetic vector potential together form a four vector, so that the two kinds of potential are mixed under Lorentz transformations.

In electrostatics

The electric potential at a point **r** in a static electric field **E** is given by the line integral

$$V_{\mathbf{E}} = -\int_C \mathbf{E} \cdot \mathrm{d}\boldsymbol{\ell}$$

where C is an arbitrary path connecting the point with zero potential to **r**. When the curl $\nabla \times \mathbf{E}$ is zero, the line integral above does not depend on the specific path C chosen but only on its endpoints. In this case, the electric field is conservative and determined by the gradient of the potential:

$$\mathbf{E} = -\nabla V_{\mathbf{E}}.$$

Then, by Gauss's law, the potential satisfies Poisson's equation:

$$\nabla \cdot \mathbf{E} = \nabla \cdot (-\nabla V_{\mathbf{E}}) = -\nabla^2 V_{\mathbf{E}} = \rho/\varepsilon_0,$$

where ρ is the total charge density (including bound charge) and $\nabla \cdot$ denotes the divergence.

The concept of electric potential is closely linked with potential energy. A test charge q has an Electric potential energy U_E given by

$$U_{\mathbf{E}} = q\, V.$$

The potential energy and hence also the electric potential is only defined up to an additive constant: one must arbitrarily choose a position where the potential energy and the electric potential are zero.

These equations cannot be used if the curl $\nabla \times \mathbf{E} \neq 0$, i.e., in the case of a *nonconservative electric field* (caused by a changing Magnetic field; see Maxwell's equations). The generalization of electric potential to this case is described below.

Electric potential due to a point charge
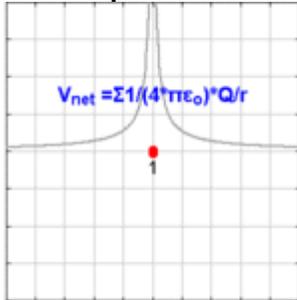
The electric potential created by a charge Q is $V = Q/(4\pi\epsilon_o r)$. Different values of Q will make different values of electric potential V (shown in the image).

The electric potential created by a point charge Q, at a distance r from the charge (relative to the potential at infinity), can be shown to be

$$V_{\mathbf{E}} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r},$$

where ϵ_0 is the electric constant (permitivity of free space). This is known as the Coulomb potential.

The electric potential due to a system of point charges is equal to the sum of the point charges' individual potentials. This fact simplifies calculations significantly, since addition of potential (scalar) fields is much easier than addition of the electric (vector) fields.

The equation given above for the electric potential (and all the equations used here) are in the forms required by SI units. In some other (less common) systems of units, such as CGS-Gaussian, many of these equations would be altered.

Generalization to electrodynamics

When time-varying magnetic fields are present (which is true whenever there are time-varying electric fields and vice versa), it is not possible to describe the electric field simply in terms of a scalar potential V because the electric field is no longer conservative: $\int_C \mathbf{E} \cdot d\boldsymbol{\ell}$ is path-dependent because $\nabla \times \mathbf{E} \neq \mathbf{0}$ (Faraday's law of induction).

Instead, one can still define a scalar potential by also including the magnetic vector potential $\mathbf{A}$. In particular, $\mathbf{A}$ is defined to satisfy:

$$\mathbf{B} = \nabla \times \mathbf{A},$$

where **B** is the Magnetic field. Because the divergence of the magnetic field is always zero due to the absence of magnetic monopoles, such an **A** can always be found. Given this, the quantity

$$\mathbf{F} = \mathbf{E} + \frac{\partial \mathbf{A}}{\partial t}$$

is a conservative field by Faraday's law and one can therefore write

$$\mathbf{E} = -\nabla V - \frac{\partial \mathbf{A}}{\partial t},$$

where *V* is the scalar potential defined by the conservative field **F**.

The electrostatic potential is simply the special case of this definition where **A** is time-invariant. On the other hand, for time-varying fields, note that

$$-\int_a^b \mathbf{E} \cdot \mathrm{d}\boldsymbol{\ell} \neq V_{(b)} - V_{(a)},$$

unlike electrostatics.

Note that this definition of *V* depends on the gauge choice for the vector potential **A** (the gradient of any scalar field can be added to **A** without changing **B**). One choice is the Coulomb gauge, in which we choose $\nabla \cdot \mathbf{A} = 0$. In this case, we obtain

$$-\nabla^2 V = \rho/\varepsilon_0,$$

where ρ is the charge density, just as for electrostatics. Another common choice is the Lorenz gauge, in which we choose **A** to satisfy

$$\nabla \cdot \mathbf{A} = -\frac{1}{c^2} \frac{\partial V}{\partial t}.$$

Units

The SI unit of electric potential is the volt (in honour of Alessandro Volta), which is why a difference in electric potential between two points is known as Voltage. Older units are rarely used today. Variants of the centimeter gram second system of units included a number of different units for electric potential, including the abvolt and the statvolt.

Galvani potential versus electrochemical potential

Main articles: Galvani potential, Electrochemical potential and Fermi level

Inside metals (and other solids and liquids), the energy of an electron is affected not only by the electric potential, but also by the specific atomic environment that it is in. When a voltmeter is connected between two different types of metal, it measures not the electric potential difference, but instead the potential difference corrected for the different atomic environments.[1] The quantity measured by a voltmeter is

called <u>Electrochemical potential</u> or <u>Fermi level</u>, while the pure unadjusted electric potential is sometimes called <u>Galvani potential</u>. The terms "voltage" and "electric potential" are a bit ambiguous in that, in practice, they can refer to *either* of these in different contexts.

References

1. **^** Bagotskii, Vladimir Sergeevich (2006). *Fundamentals of electrochemistry*. p. 22. <u>ISBN</u> <u>978-0-471-70058-6</u>.
- Griffiths, David J. (1998). *Introduction to Electrodynamics* (3rd. ed.). Prentice Hall.<u>ISBN</u> <u>0-13-805326-X</u>.
- Jackson, John David (1999). *Classical Electrodynamics* (3rd. ed.). USA: John Wiley & Sons, Inc. <u>ISBN</u> <u>978-0-471-30932-1</u>.
- Wangsness, Roald K. (1986). *Electromagnetic Fields* (2nd., Revised, illustrated ed.). Wiley. <u>ISBN</u> <u>978-0-471-81186-2</u>.