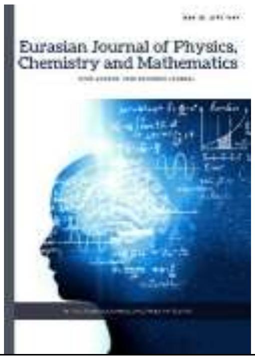

The Electric Field and its Strength

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ABSTRACT

In this article, the electric field strength is explained in detail through the Gauss theorem and other examples.

Keywords: Gauss theorem, Coulomb's law, electric charge, positive charge, electric field, vector

Introduction

According to Coulomb's law, charges located at a certain distance from each other interact through space. The area of space in which the effect of electric forces around an electric charge is felt is called the electric field of this charge.

To study the characteristics of the electric field, the concept of "test charge" is introduced. The amount of the "test charge" should be as small as possible, so that it does not change the properties of the field under test with its field. Let's place a test charge ($+q_c$) at the point determined by the radius - vector $\vec{r}$, the position of the charge concerning +q (Fig. 1).

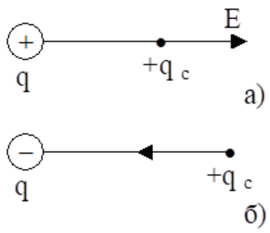

Figure 1.

We find that the Coulomb force acts on this charge as follows.

$$F = \frac{1}{4\pi\varepsilon_0} \cdot \frac{qq_c}{r^2} \cdot \frac{\vec{r}}{r} \qquad (1)$$

$\frac{F}{q_c}$ the ratio unit characterizes the force acting on the positive charge, which is independent of the size of the test charge. Therefore, we take this ratio as a quantity defining the electric field and denote it by Y_e.

$$\vec{E} = \frac{F}{q_c} = \frac{4}{4\pi\varepsilon_0} \cdot \frac{q}{r^2} \cdot \frac{\vec{r}}{r} \qquad (2)$$

The vector quantity in relation (2) is called electric field strength.

Therefore, the field intensity at an arbitrary point of the electric field is understood as a physical quantity characterized by the force exerted on a unit charge brought to this point.

The main part

The electric field strength is a vector quantity, the direction of which is determined by the direction of the force acting on a unit positive charge brought to the tested point of the field (Fig. 1). If the charge q is positive, the direction Y_e is directed away from the charge along the grid line connecting the tested point of the field, or towards the charge when q is negative.

In SI, the unit of electric field strength is the newton coulomb (N/Kl) or volt meter (V/m).

If the electric field is created by several charges, the resulting field strength is equal to the vector sum of the electric field strengths created by individual particles, i.e.:

$$E = E_1 + E_2 + \dots E_n \sum_{i=1}^{n} E_i \qquad (3)$$

Expression (3) expresses the principle of superposition (addition) of fields.

Lines of tension. Gauss' theorem

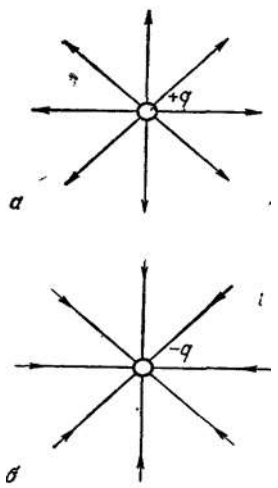

Figure 2.

To represent the electric field graphically, the magnitude of the lines of force is entered. Voltage lines are drawn based on the following two conditions:

1. The test applied to an arbitrary point of the voltage line must coincide with the direction of the electric field voltage vector at this point.
2. When choosing the density of lines, the number of lines passing through a unit surface perpendicular to the lines should be equal to the numerical value of the vector Y_e. Electric field lines have a beginning and an end, starting with a positive charge and ending with a negative charge.

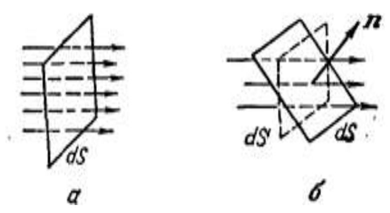

Figure 3.

If the intensity E is the same at all points of the electric field, the electric field is said to be homogeneous.

Figures 3a and b show the electric field of positive and negative point charges. Lines of the intensity of point charges consist of radial mesh lines starting from the surface of a positive charge and ending at the surface of a negative charge or extending from a positive charge to infinity.

The number of lines of force crossing a surface located in an electric field is called the flux F of the field passing through this surface.

Now let's determine the value of F. For this, let's take an elementary surface dS placed perpendicular to the direction of the stress lines (Fig. 9.3a). dS is the number of stress lines crossing the surface equal to EdS. The expression EdS is called the flux of the stress vector passing through the surface dS. If the surface is not perpendicular to the field lines, and the field strength is different in its different parts, then the surface should be divided into dS sub-surfaces, each of which can be assumed to have a constant field strength. In this case, the voltage-current passing through the elementary surface is equal to:

$$d\Phi = E\,d\,S' = E\,d\,S\cos\alpha = E_n d\,S \qquad (4)$$

Hereα- the angle between the stress line and the normal n transferred to the surface dS. dS′ and dS is the projection of the surface onto the plane perpendicular to the stress lines. In that case, the current of the field strength passing through the entire surface is represented by the sum of elementary currents dF. We write this by integration as follows:

$$\Phi = \int_S d\Phi = \int_S E_n dS \qquad (5)$$

Let us find the flux of vector E through a spherical surface of radius r. Recalling (1).

$$E_n = |E| = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2} \qquad (6)$$

on the other hand, the total surface area of a spherical surface with a radius r is equal to $4\pi r^2$. As a result

$$\Phi = \oint_S E_n dS = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\cdot 4\pi r^2 = \frac{q}{\varepsilon_0} \qquad (7)$$

This expression represents the flux of the vector Y_e passing through a spherical surface surrounding a single-point charge. Now let there be point charges q_1, q_2, etc. with arbitrary values inside a closed surface.

Based on (2) according to the principle of superposition of fields:

$$E_n = E_{n1} + E_{n2} + \ldots E_{n\kappa}\sum_{i=1}^{\kappa} E_{ni} \qquad (8)$$

Using (8) and (6), we get:

$$\Phi = \oint_S E_n dS = \oint_S \sum_{i=1}^{\kappa} E_{ni} dS = \sum_{i=1}^{\kappa}\oint_S E_{ni} dS \qquad (9)$$

This expression characterizes the flow of E_{ni} - the electric field strength vector generated by a point charge *i* through an arbitrary closed surface *S* surrounding this charge. Based on the relation (5) above:

$$\oint_S E_{ni} dS = \frac{q_i}{\varepsilon_0}$$

Taking this into account, we write (9) as follows:

$$\Phi = \oint_S E_n dS = \frac{1}{\varepsilon_0}\sum_{i=1}^{n} q_i \qquad (10)$$

This expression is called Gauss' theorem. This theorem can be described as follows: the flow of the electric field intensity vector through a closed surface of arbitrary shape is the algebraic sum of the charges located inside this surface is equal to the ratio of ε_0.

Using Gauss's theorem, let's find the electric field strength of a uniformly charged infinite plane with surface charge density $+\sigma$, which is equal to:

$$E = \frac{\sigma}{2\varepsilon_0} \qquad (11)$$

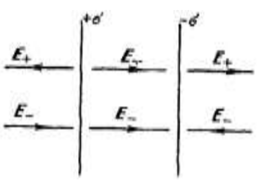

Figure 4.

Here $\sigma = \frac{q}{S}$ charge is the surface density. The electric field between two mutually parallel charged infinite planes is the electric field strength.

$$E = E_+ + E_- \frac{\sigma}{2\varepsilon_0} + \frac{\sigma}{2\varepsilon_0} = \frac{\sigma}{\varepsilon_0} \qquad (12)$$

So, the resulting field will be the sum of the fields created by both charged planes (Fig. 4). Since the value and direction of E at all points of the field between these two planes are the same, this field is called a homogeneous field.

The work of electrostatic field forces

Let's calculate the work done by the field forces in moving the charge q' located in the field of fixed point charge q from point 1 to point 2. It is equal to the work done on an elementary path of length dl (Fig. 5).

$$dA = F\,dl\cos\alpha = \frac{1}{4\pi\varepsilon_0}\cdot\frac{qq'}{r^2}dl\cos\alpha = \frac{1}{4\pi\varepsilon_0}\cdot\frac{qq'}{r^2}dr$$

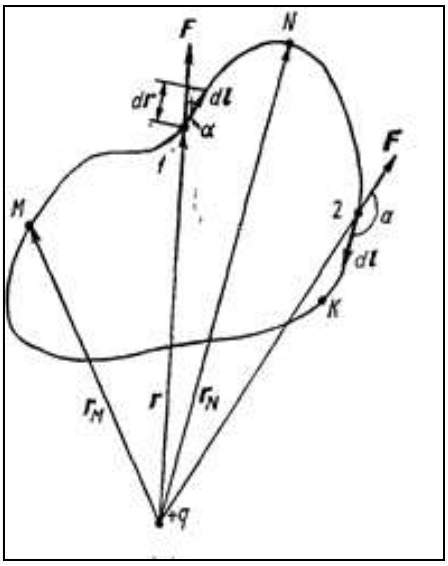

Figure 5.

Here dr = dl cosα. We find the work done on the path between points 1-2:

$$A = \int_1^2 dA = \frac{qq'}{4\pi\varepsilon_0}\int_{r_1}^{r_2}\frac{dr}{r^2} = \frac{1}{4\pi\varepsilon_0}\left(\frac{qq'}{r_1} - \frac{qq'}{r_2}\right) \qquad (13)$$

It is known from the mechanics part that the work done by field forces on a closed path is zero, i.e.

$$\oint_l q' E_l dl\cos\alpha = 0$$

here, Yei-Ye is the projection of the vector in the direction of the elementary displacement dl (the circle in the symbol of the integral indicates that the integral is taken over a closed contour).

If we make the integral representing the work equal to zero and reduce the constant quantity q′, we get the following relationship:

$$\oint_{\ell} E_i dl = 0 \quad (14)$$

this relation must hold for any closed loop.

So, from relation (11) it can be seen that the electric field is a potential field, and the circulation of the intensity vector of this field along an arbitrarily closed circuit is equal to zero.

Using the above considerations, the work expressed by formula (10) can be expressed as the difference of potential energy at points 1 and 2 of the charge field q′.

$$A_{12} = \frac{1}{4\pi\varepsilon_0}\frac{qq'}{r^1} - \frac{1}{4\pi\varepsilon_0}\frac{qq'}{r_2} = W_{\Pi 1} - W_{\Pi 2}$$

It is located at points 1 and 2 potential energy of the charge in the charge field q′:

$$W_{n1} = \frac{1}{4\pi\varepsilon_0}\frac{qq'}{r^1}; \quad W_{n2} = \frac{1}{4\pi\varepsilon_0}\frac{qq'}{r_2}$$

it follows that it is equal. In general, q′ potential energy of the field when it is located at an arbitrary point

$$W_{\Pi} = \frac{1}{4\pi\varepsilon_0}\frac{qq'}{r} \quad (15)$$

Various test charges q′, q″, etc., have energies W'_n, W''_n, etc. at a certain point of the field. However, W_n/q' is relatively the same for all charges. The following quantity is called potential.

$$\phi = \frac{W_n}{q'} \quad ёки \quad \phi = \frac{1}{4\pi\varepsilon_0}\frac{q}{r} \quad (16)$$

If the electric field is generated by a system of charges, the resulting potential is equal to the algebraic sum of the potentials at the point under investigation.

$$\phi = \phi_1 + \phi_2 + \ldots + \sum \phi_i \quad (17)$$

Using (16) and (17), we get:

$$\phi = \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{n}\frac{q_i}{r_i} \quad (18)$$

using (16).

$$W_{\Pi} = q \cdot \phi \quad (19)$$

we make, therefore, the work done by the field forces on the charge q can be expressed by the potential difference:

$$A_{12} = W_{\Pi 1} - W_{\Pi 2} = q(\phi_1 - \phi_2) \quad (20)$$

or

$\varphi_\infty = 0$, then

$$A_\infty = qj \quad (21)$$

Using this, the potential can be defined as follows: the potential of an arbitrary point of the electric field is defined as the quantity characterized by the work required to move a unit of positive charge from this point to infinity.

The division between the strength of the electric field and the potential let's see. If q'the work done when the test charge is moved away by the field forces by a distance dr, F . will be equal to dr. This work q'causes the potential energy of the charge to decrease to dWP. Thus, considering equation (13).

$$Fdr = -dW_{\Pi}$$

or

$$F = \frac{dW_{\Pi}}{dr}$$

This expression can be expressed as 'the amount of charge being transferred to both sides q′ as for:

$$\frac{F}{q'} = -\frac{d\left(\frac{dW^1}{q'}\right)}{dr}$$

from this

$$E = -\frac{d\phi}{dr} \quad (22)$$

we derive the expression. In (22) $\frac{d\varphi}{dr}$ the expression is called potential gradient, i.e. (gradφ), then we can write (22) as follows:

$$E = -grad\phi \quad (23)$$

Conclusion

Thus, the electric field strength is equal to the gradient of the potential obtained with the opposite sign. Here, the negative sign indicates that Ye is oriented in the direction of decreasing potential.

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