DOI 10.12851/EESJ201512C08ART01

Michail G. Kolonutov,
ScD, chief engineer,
Novgorodaudit-ENERGO

Fundamentals of Systematic Theory of Electrical Phenomena

Key words: theory of electricity, electric field, electrical quantities, laws of electromagnetism, force interaction, Lorentz transformation, Bohr's postulate, energy emission.

Annotataion: The proposed theory is based on a systematic principle in accordance with which the status of electrical quantity is assigned to those quantities only that may be expressed by partial derivatives of electric field energy with respect to charge, spatial coordinate and speed of charge carriers. The systematic character of the proposed quantities and strict mathematical interrelation between them forms a new theoretical picture of physics of electrical phenomena that is able to provide explanations even for such phenomena that had rendered electromagnetic theory helpless.

Introduction

Nowadays, the science that studies electrical phenomena is in a state of depression. All the worthwhile results lying at its basis were obtained a hundred or more years ago, at the first stage of theory development. That was the time of discovery of experimentally reproduced stable phenomena electrical by nature, followed by their description in the form of a particular mathematical dependence. It resulted in lots of empirical laws, i.e. the Biot-Savart law, Ampere's law, Faraday's law, the law of total current etc., constituting the core of modern theory of electricity. At this stage, the science acquired a seriously prescriptive character, answering, for the most part, the how-questions. As for the why-questions, they remained unanswered. Instead of detecting and analyzing the underlying physical causes, the science at this stage became engaged in inventing formal constructions that were able, to some extent, generalize the empirical laws.

Maxwell's equations are among the many examples; they were used quite successfully in a number of engineering fields, nevertheless failing to provide adequate description of such problems as, for instance, atomic stability, energy transformation in an electromagnetic wave, force interaction of moving charge carriers. These and a number of other problems exposed essential incompleteness of the theory, which is a major restriction to its deductive potential.

One more example demonstrating formal construction of the theory of electricity is the Lorentz transformation that had been borrowed from pure mathematics. In absence of any physical grounds whatsoever, the Lorentz transformations were applied to the description of electromagnetic phenomena and became a formal basis for prediction of a multitude of alleged mystical properties of material objects. Degeneration of physics into a branch of mathematics employing the terminology of physics is a path that, instead of adequate description of real physical phenomena, leads to the thought that the behavior of material objects must obey some formal constructs. For example, the atom is considered to be stable not because electrons are kept from falling on the nucleus by some physical cause, but because this is prevented by the laws of quantum mechanics and the indeterminacy principle. Anyway, this is what is written by R. Feynman (3, p.10).

A great number of initially empirical laws, as well as the absence of a uniform, physically grounded treatment of their origin, is the major shortcoming of electromagnetic theory holding back its further development. As a result, various modifications of the theory emerged. Some of them lead beyond Maxwell’s equations, others alter the properties of the vacuum, endowing it with certain specific features. These problems are dealt with in works (1, 2, 7, 8, 9). The most detailed elaboration of a revised electromagnetic field theory is found in book (8), which is based on the concept of an electrically polarized state of the vacuum that gives rise to a local electric charge and, correspondingly, a nonzero electric field divergence. In articles (15, 20) and in a number of other works the physical properties of a hydrogen atom are also explained by polarization of the vacuum, but as opposed to (8), polarization is not considered to be a constant attribute of the vacuum, but arises only under the influence of a strong magnetic field.

Nevertheless, such modifications do not change the theory’s prescriptive character. They just fill in the gaps that exist in the theory without affecting its foundation. The general way for development of the theory of electricity lies in making its propositions explanatory, not prescriptive. This explanatory character may only be achieved on condition that lots of the existing empirical laws and formal constructions are presented as the manifestation of their common physical nature under certain conditions. Only in this case, guided by physical, not formal content, one may get an informative answer to the question “Why?” without the risk of getting an answer in the form of a reference to one of the laws that were formulated by the founders a hundred or more years ago. It is indispensable that the theory’s foundation is represented by a systematically arranged complex of basic concepts that constitute the underlying carrier set of the theory, along with a great number of quite simple relations between these concepts – signature of the theory. However, the existing set of physical quantities that characterize the electric field is quite far from any consistency. To a considerable degree, it sprang up from a great many experiments, and naturally, it reflects experimental techniques of each of them, not the specific character of the electric field as the object of research. The desired systematic character of the set of basic concepts may only be achieved by such a method of electric field parameterization that is based on a single, but the most general physical characteristic inherent in the electric field – its energy. The term "parameterization" here denotes a process of determining (designing) the quantities that reflect the essential properties of the electric field.

The purpose of this work is to develop the fundamentals of a Systematic Theory of Electrical Phenomena (STEP) that would fully reflect their common physical nature. This theory is an alternative to the set of empirical laws along with their formal mathematical generalizations that make up the foundation for the modern doctrine of electrical phenomena.

Verification of the proposed theory has been made by way of demonstrating the compliance of its predicted results with those entailed by the empirical laws constituting the basis of electromagnetism.

Relevance of the theory and its potential were demonstrated by its ability to solve a number of problems which the classical theory of electricity was unable to tackle.

The first section of the study sets forth the basic points that serve as the foundations of the theory; in particular, it provides a more refined concept of the electric field, introduces the concept of an equivalent source of the electric field, and describes the method of parameterization that permits to determine in a systematic way the physical quantities characterizing the properties of the electric field.

The basic physical quantities as the manifestation of the electric field energy are determined in the second, third and fourth sections of the work by respective use of a potential or kinetic component and total energy of the field.

The fifth section of the work is aimed at providing theoretical grounding for such empirical laws of electromagnetism as Ampere's law, Faraday's law, the Lorentz force. These laws cease to be a generalization of experimental data and acquire the status of analytical consequences of the theory, thus confirming the validity of STEP.

The sixth section presents the solutions of problems unsolvable in the classical theory. An opinion has been refuted of the violation of Newton's third law which is alleged to be characteristic of interactions of charged bodies. A condition has been obtained under which emission occurs in case of accelerated motion of charge carrier. The solution is given for "electromagnetic paradox" that is connected with the opinion of its insolvability without resorting to the methods of relativistic electrodynamics.

1 Method of Electric Field Parameterization

1.1 More accurate definition of the term "electric field"

Any theory must be based on well-defined concepts and unambiguous interpretation of the terms employed. Unfortunately, the theory of electromagnetism is not remarkable for its stringency. It can be exemplified by the term "field". The term is used by mathematicians to denote an algebraic structure that is a commutative ring which contains a multiplicative inverse for every nonzero element. In this interpretation, the use of the term is quite reasonable as, for instance, in a phrase "vector field". Thus it is asserted that there exists an algebra whose carrier set is represented by a multitude of vectors while the signature of algebra consists of operations with predetermined properties. The field as an algebraic structure is a product of human mental efforts and therefore it presents an ideal object (in a philosophical sense). Such field, being a mental construction, is unable to make any impact on objects of material world.

The term "field" acquires quite a different meaning in a phrase "electric field". Here the field is a material substance existing regardless of man and independently. This field, as opposed to a mathematical field, is capable of forceful influence on the objects of material world such as charged and even uncharged objects.

Incomprehension of the homonymous character of the term "field" leads to quite absurd statements that can be found not only in articles but also in undergraduate textbooks. The following statement is an example of it: "Let us call this vector function an electric field" (16, p. 33) whence it follows that mental constructions (vector functions) are capable of influencing various material bodies in some mystic way. Another up-to-date textbook (4, p. 53) reads as follows: "…if there are no electric charges in a cavity, its electric field equals zero". Obviously, the author considers the electric field to be some mathematical quantity, as material substances are usually spoken of in terms of “presence” or “absence”. Water may be absent in a desert, but it cannot be equal to zero.

One more methodological mistake of the electromagnetic theory can be demonstrated by a statement (4, p. 21) that if the field intensity inside a uniformly charged surface equals zero, the electric field within this space is absent. Hence a rhetorical question: what was the author’s rationale when on the basis of potential gradient being equal to zero the conclusion is made that the field is inexistent as a physical phenomenon? On a mountain plateau, gravitational potential gradient equals zero, but it does not at all mean that the mountain itself has disappeared. In conclusions of this kind no difference is made between the concepts of “existing” and “manifesting in the form of forceful influence upon foreign charged bodies.”

Further in this work the electric field will always be taken to mean a material continuum that is indissolubly related to charge carriers and is capable of acting by force on charged bodies, and in so doing obeys the laws of mechanics.

Regarding the last of the above listed field properties it should be noted that an opinion became firmly established in contemporary physics (10, pp. 133-136; 12, p. 12) on inapplicability in principle of the laws of classical mechanics to electrical phenomena. Failure to apply mechanics for solving a particular problem of whether imaginary ether can be the carrier of electromagnetic oscillations could have initiated the search for some other carrier substance, but instead a misconception was established that mechanics as such is unfit for application to electrical phenomena. To refute this misconception, the study (18) shows that electrodynamics may well be constructed as the mechanics of the electric field, which allows obtaining results of a much more general character as compared to Maxwell’s equations.

1.2 Equivalent sources of the electric field

It is universally recognized that if charge Q of a point field source is spread evenly over the surface of a sphere, with the centre at the place of this source location, then the field force exerted on test particles located at the points in space outside the sphere will not change. The charged sphere and the point field source are in this sense indistinguishable, and therefore interchangeable, i.e. equivalent. Hence it follows that all spherical charge carriers with radius $R > 0$ and the centre at the point of field source location will be equivalent to some point field source if their surface charge density σ satisfies the condition (1.1),

$$\sigma = Q/4\pi R^2, \tag{1.1}$$

and observation points are at a distance of $r \geq R$.

In case of linear charge carriers, equivalent carriers are all cylinders of revolution coaxial with a linear charge carrier with linear density λ, whose surface charge density is

$$\sigma = \lambda/2\pi R \tag{1.2}$$

Among the set equivalent sources (having the same charge and the same force action upon charged bodies), one source may be singled out whose surface passes through the observation point. Therefore, the quantities that reflect the properties of the surface of some equivalent source may be considered as the quantities characterizing the field properties for all other equivalent sources with a smaller radius. Thus the system of parameters characterizing an electric field at distance R from a point field source may be constructed as a set of quantities reflecting the properties of the surface of some virtual equivalent source with radius R.

1.3 Energy of the electric field

Transfer of like charge carriers from one formerly uncharged body to another results in appearance of an electric field in the vicinity of these bodies. Separation of charge carriers requires work, which is accumulated as energy W_{es} of the created electrostatic field. The store of energy in this field depends on distance R between the bodies and the amount of charge Q accumulated on the bodies in the process of charge separation, so the energy, all other things being equal, may be considered as the function of two arguments, $W_{es}(Q, R)$.

In case when a charged body is moving relative to the observer, the electric field is bound to move along with it at a certain speed *v*. As every moving material object, the electric field in this case acquires kinetic energy whose amount is now the function of three arguments, $W_{ek}(Q, R, v)$. Following Maxwell (11, p. 204) we will call this energy electrokinetic. The carrier of this energy is the electrokinetic field created in the vicinity of a charge carrier in course of its motion. Just like the electrostatic field, it is capable of force action on other bodies, thus presenting a material substance.

1.4 Method of parameterization

In the author's opinion, the only way to create a system of physical quantities that are capable of reflecting the properties of the electric field (just like any other continuum, i.e. gravitational field), which would reproduce force interaction of charged bodies is to interpret each of the derivatives of functions $W_{es}(Q, R)$ and $W_{ek}(Q, R, t)$ with respect to one or several arguments as certain physical quantities of such system.

All that follows is an illustration of the suggested procedure of parameterization of the electric field and the application of its results.

2 Main parameters of the electrostatic field

2.1 Electrostatic field of a point charge carrier

2.1.1 Energy of the electrostatic field

Using Coulomb's law, let us determine the energy stored in the electric field of a spherical capacitor during its charging. Let the charging process be realized by reiterated transfer of elementary charge Δqc of the capacitor's outer sphere to the inner, initially discharged, sphere until this sphere acquires charge *Q*.

While at its first step the process requires no work, $\Delta A_1 = 0$, at the second step for displacement of charge carriers Δq to the distance Δr work ΔA_2 is required, which is determined by the relation

$$\Delta A_2 = \frac{\Delta q \Delta q}{4\pi\varepsilon_0 r^2}\Delta r \,. \tag{2.1}$$

At the next step, transferring the next portion of charge will require work ΔA_3,

$$\Delta A_3 = \frac{(\Delta q + \Delta q)\Delta q}{4\pi\varepsilon_0 r^2}\Delta r. \tag{2.2}$$

At the *n*-step there is increment work ΔA_n,

$$\Delta A_{\mathrm{n}} = \frac{(\mathrm{n}-1)\Delta q}{4\pi\varepsilon_0 r^2}\Delta q \Delta r = \frac{q}{4\pi\varepsilon_0 r^2}\Delta q \Delta r\,. \tag{2.3}$$

Energy W_{es} stored in the electrostatic field of the capacitor is equal to work delivered during its charging, taken with the opposite sign. Therefore, integrating the last expression for distance *r* going from the outer sphere radius R_0 to the inner sphere radius *R*, and for charge from zero to *Q*, we will arrive at the energy in question,

$$W_{\mathrm{es}} = -\int_0^Q \int_{R_0}^R \frac{q}{4\pi\varepsilon_0 r^2} dr dq = \frac{Q^2}{8\pi\varepsilon_0}\left(\frac{1}{R} - \frac{1}{R_0}\right) \tag{2.4}$$

2.1.2 Potential

Partial derivative $\partial W_{es}/\partial Q$ accounts for energy increase with unit increment of field source charge, i.e. a quantity that equals the work that can be potentially delivered by the field as its charge is decremented by one. It is natural to call such physical quantity electrostatic potential ϕ_{es} of the equivalent source,

$$\varphi_{es} \stackrel{\text{def}}{=} \frac{\partial W_{es}(Q,R)}{\partial Q} = \frac{Q}{4\pi\varepsilon_0}\left(\frac{1}{R} - \frac{1}{R_0}\right). \tag{2.5}$$

It is notable that with such definition of the potential there is no need to resort to the concept of “test charge”.

2.1.3 Field source capacitance

Second derivative of energy W_{es} with respect to charge *Q* does not depend on the charge itself, therefore it is a constructive characteristic of the electric field source. In an attempt to stick to the presently accepted terminology, we will call the concerned derivative the inverse capacitance of the field source,

$$C^{-1} \stackrel{\text{def}}{=} \frac{\partial^2 W_{es}}{\partial Q^2} = \frac{\partial \varphi_{es}}{\partial Q} = \frac{1}{4\pi\varepsilon_0}\left(\frac{1}{R} - \frac{1}{R_0}\right). \tag{2.6}$$

From relation (2.6) considering (2.5) an expression may be easily derived that connects the potential with the amount of charge,

$$\varphi_{es} = QC^{-1}, \tag{2.7}$$

which shows that in the classical theory of electricity, the physical quantity characterizing the proportionality of potential and charge was accepted to be the quantity reciprocal to the second partial derivative of energy with respect to charge, not the derivative itself, which would have been logical.

2.1.4 Field intensity

Potential gradient, or mixed derivative of energy with respect to charge and space coordinates, determines the electric field vector:

$$\mathbf{E}_{es} \stackrel{\text{def}}{=} -\mathbf{grad}\left(\frac{\partial W_{es}(Q,R)}{\partial Q}\right) = -\mathbf{grad}\varphi_{es} = \frac{Q}{4\pi\varepsilon_0 R^2}\mathbf{1}_r. \qquad (2.8)$$

where 1_r is the unit vector of the radial axis of a spherical coordinate system.

2.1.5 Flux of pressure force

The derivative of energy with respect to the equivalent source radius, taken with the opposite sign, is a scalar quantity that characterizes total field force exerted on the surface of this source.

$$P \stackrel{\text{def}}{=} -\frac{\partial W_{es}}{\partial R} = \frac{Q^2}{8\pi\varepsilon_0 R^2}\,. \qquad (2.9)$$

Due to symmetry, this effect should be evenly distributed over the surface, therefore it is logical to talk about flux P of pressure force p,

$$\mathbf{p} \stackrel{\text{def}}{=} -\frac{\partial P}{\partial s}\mathbf{1}_{\mathrm{n}} = \frac{Q^2}{32\pi^2\varepsilon_0 R^4}\mathbf{1}_{\mathrm{n}}, \qquad (2.10)$$

where 1_{n} is the unit vector of outer normal to surface element ds in a considered surface point.

2.1.6 Field energy density

Since the electric field is the carrier of energy W_{es}, then its every point must be characterized by energy density w_{es}. These two quantities, W_{es} and w_{es}, are connected by the apparent relation:

$$W_{es} = \int_V w_{es}dV = \int_R^{R_0} w_{es}\,4\pi r^2\,dr, \qquad (2.11)$$

where r is the reference radius, $R \le r \le R_0$.

Interchanging the limits of integration, we will find the derivative of function W_{es} with respect to the upper limit,

$$\frac{\partial W_{es}}{\partial R} = -\,w_{es}\,4\pi r^2\,. \qquad (2.12)$$

Let us assume $r = R$ in this expression and compare formulas (2.12) and (2.09). As a result of comparison, we arrive at a relation that determines the density of electrostatic field energy on the surface of the equivalent source,

$$w_{es} = \frac{Q^2}{32\pi^2\varepsilon_0 R^4}. \qquad (2.13)$$

Energy density (2.13) has turned out to be equal to the modulus of pressure force (2.10).

If energy density is expressed in terms of electrostatic field intensity (2.8), we will obtain

$$w_{es} = \frac{1}{2}\varepsilon_0 E_{es}^2. \qquad (2.14)$$

In the classical theory of electricity (19, p. 147), relation (2.14) is called one of *the basic postulates* of a macroscopic theory of electricity. Here, instead of being postulated, this relation is being formally derived, and it follows from the derivation that the said relation accounts for energy density only at the points that constitute the surface of an equivalent source.

Let us restrict electrostatic field parameterization for point charge carrier by introducing the quantities listed above and move on to determining the analogous quantities representing the properties of the electric field of an extended linear field source.

2.2 Electrostatic field of a linear charge carrier

2.2.1 Field energy

Let us assume there is a cylindrical capacitor whose outer plate radius equals R_0 and inner plate radius is R. The outer plate potential will be considered to equal zero. Using Coulomb's law, it is easy to demonstrate that in process of charge separation an electric field is created between the capacitor's plates, and each of its unit lengths has energy $W_{es}(\lambda, R)$,

$$W_{es} = \frac{\lambda^2}{4\pi\varepsilon_0}\ln\frac{R_0}{R}, \qquad (2.15)$$

where λ is linear charge density.

2.2.2 Potential

Let us define the potential as a quantity equal to work that the field is potentially capable of exerting when its linear charge density changes by one. In accordance with this definition, the formal expression of the potential is a partial derivative of energy W_{es} (2.15) with respect to linear charge density λ,

$$\varphi_{es} \stackrel{\text{def}}{=} \frac{\partial W_{es}}{\partial\lambda} = \frac{\lambda}{2\pi\varepsilon_0}\ln\frac{R_0}{R}. \qquad (2.16)$$

2.2.3 Capacitance

The second derivative of energy (2.15) with respect to charge density λ characterizes the capacitor's geometry and represents inverse capacitance of a unit length capacitor,

$$C^{-1} \stackrel{\text{def}}{=} \frac{\partial^2 W_{es}}{\partial \lambda^2} = \frac{1}{2\pi\varepsilon_0} \ln\frac{R_0}{R} \,. \tag{2.17}$$

2.2.4 Field intensity

Let us define the electric field vector as a characteristic of spatial distribution of the potential reflected by gradient vector taken with the opposite sign,

$$\mathbf{E}_{es} \stackrel{\text{def}}{=} -\mathbf{grad}\varphi_{es} = \frac{\lambda}{2\pi\varepsilon_0 R}\mathbf{1}_r \,. \tag{2.18}$$

2.2.5 Flux of pressure force

Partial derivative with respect to radius *R* taken with the opposite sign is flux *P* of pressure force through the surface of capacitor's inner plate,

$$P \stackrel{\text{def}}{=} -\frac{\partial W_{es}}{\partial R} = \frac{\lambda^2}{4\pi\varepsilon_0 R} \,. \tag{2.19}$$

Pressure force p will be found by differentiating flux *P* with respect to the plate area,

$$\mathbf{p} \stackrel{\text{def}}{=} -\frac{\partial P}{\partial s}\mathbf{1}_{\mathrm{n}} = \frac{\lambda^2}{8\pi^2\varepsilon_0 R^2}\mathbf{1}_{\mathrm{n}}. \tag{2.20}$$

2.2.6 Field energy density

Energy W_{es} stored in the capacitor's electric field and density w_{es} of this energy are connected by relation (2.21):

$$W_{es} = \int_V w_{es} dV = \int_R^{R_0} w_{es}\, 2\pi r\, dr, \tag{2.21}$$

where *r* is the reference radius, $R \le r \le R_0$.

Interchanging the limits of integration, we will find the derivative of function W_{es} with respect to the upper limit,

$$\frac{\partial W_{es}}{\partial R} = -\, w_{es}\, 2\pi r \,. \tag{2.22}$$

Let us assume $r = R$ in this expression and compare formulas (2.22) and (2.19). As a result of comparison, we arrive at a relation that determines the density of electric field energy on the surface of the equivalent source,

$$w_{es} = \frac{\lambda^2}{8\pi^2\varepsilon_0 R^2}. \tag{2.23}$$

Energy density, as is the case with a point field source, is equal to the modulus of pressure force (2.20). If density (2.23) is expressed in terms of electric field intensity (2.18), the classical result will be obtained, which as was noted in point 2.1.6, is a postulate in contemporary theory.

Restricting the electrostatic field parameterization by the quantities introduced, let us move on to parameterization of the electric field of moving charge carriers.

3 Basic parameters of the electrokinetic field

3.1 Electrokinetic field of a point charge carrier

3.1.1 Electrokinetic energy of the field

Assume there is a spherical charge carrier located at an infinitely large distance from all other charge carriers. The electric field energy of such charge carrier may be found from formula (2.4) if we put $R_0 \to \infty$:

$$W_{es} = \frac{Q^2}{8\pi\varepsilon_0 R}. \tag{3.1}$$

In accordance with the Einstein relation, the electric field mass *m* of this charge carrier may be expressed by the relation,

$$m = \frac{W_{es}}{c^2} = \frac{Q^2}{8\pi\varepsilon_0 c^2 R}. \tag{3.2}$$

Suppose that a charge carrier is moving at a speed of $v(t)$ along the z-axis of a cylindrical coordinate system (r, θ, z). The electric field is always inseparably connected with the carrier and therefore will move along with it. The lag of field motion with respect to the carrier’s motion will be disregarded.

Let us define the electrokinetic energy of the field by means of a formula that is well-known from mechanics,

$$W_{ek} = \frac{1}{2}mv^2 = \frac{1}{2}W_{es}\frac{v^2}{c^2} = \frac{Q^2}{16\pi\varepsilon_0 R}\frac{v^2}{c^2}. \tag{3.3}$$

Unlike in electrostatics, distance R is changing now in relation to time and speed $R = \left(r^2 + \left(z - \int_0^t v(t)\,\mathrm{d}t\right)^2\right)^{1/2}$. Figure 1 is a diagram explaining this relation. The subscript “es” when indicating quantities, i.e. W_{es} in formula (3.3) will be used to denote the quantities that would characterize the field when the charge carrier is located at some fixed distance R = const from the observation point in a static condition.

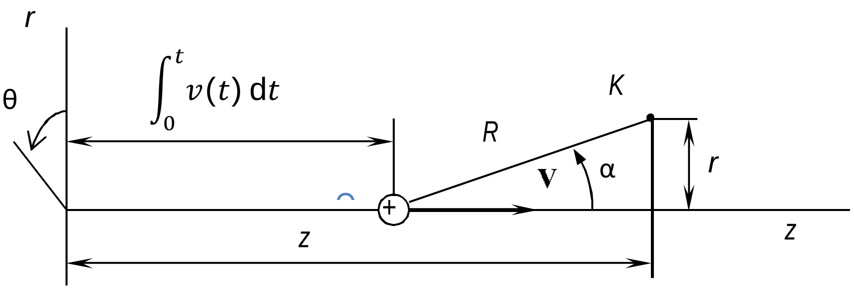


Figure 1

3.1.2 Potential

Let us give a name of the electrokinetic potential to a quantity expressed by the derivative of electrokinetic energy W_{ek} with respect to charge,

$$\varphi_{ek} \stackrel{\text{def}}{=} \frac{\partial W_{ek}}{\partial Q} = \frac{Q}{8\pi\varepsilon_0 R}\frac{v^2}{c^2} = \frac{1}{2}\varphi_{es}\frac{v^2}{c^2}\,. \tag{3.4}$$

This quantity equals the change in electrokinetic energy per unit charge increment of the carrier that has created the field.

3.1.3 Pulse

Let us define the electrokinetic field pulse as a physical quantity reflecting a change in the field energy referenced to the unit increment of its speed. Mathematical expression of this quantity is a partial derivative of field energy with respect to speed,

$$\mathbf{G} \stackrel{\text{def}}{=} \frac{\partial W_{эk}}{\partial v}\mathbf{1}_{\mathbf{v}} = \frac{Q^2\mathbf{v}}{8\pi\varepsilon_0 R c^2} = m\mathbf{v}. \tag{3.5}$$

3.1.4 Vector potential

Vector potential **A** characterizes the change in an electrokinetic field pulse with the change in the amount of charge or, which is the same, the change in the electrokinetic potential with the change in the speed. For its calculation, a mixed partial derivative must be taken of energy with respect to charge and speed,

$$\mathbf{A} \stackrel{\text{def}}{=} \frac{\partial \mathbf{G}}{\partial Q} = \frac{\partial \varphi_{ek}}{\partial v} = \frac{\partial^2 W_{ek}}{\partial Q\, \partial v}\mathbf{1}_{\mathrm{v}} = \frac{Q\mathbf{v}}{4\pi\varepsilon_0 R c^2}\,. \tag{3.6}$$

The latter expression clearly demonstrates the physical significance of the vector potential as electrokinetic energy per unit charge of the carrier that is moving at a unit speed. Contrary to this definition, electromagnetic theory considers the vector potential as a mathematical quantity only, whose physical significance merits neither explanation nor discussion.

3.1.5 Intensity

Force function of the electrokinetic field will be called intensity. It must depend both on a spatial characteristic of the field, which is formally expressed by the gradient of the electrokinetic potential, and on the character of field motion, which is determined by a change in the vector potential. For that reason, the electrokinetic field intensity will be defined as a quantity equal to the sum, taken with the opposite sign, of the electrokinetic potential gradient and the derivative of the vector potential with respect to time,

$$\mathbf{E}_{ek} \stackrel{\text{def}}{=} -\left(\mathbf{grad}\varphi_{ek} + \frac{d\mathbf{A}}{dt}\right) = \frac{1}{2}E_{es.r}\frac{v^2}{c^2}\mathbf{1}_r - \frac{1}{2}E_{es.z}\frac{v^2}{c^2}\mathbf{1}_z - \frac{\varphi_{es}a}{c^2}\mathbf{1}_z\,, \tag{3.7}$$

where $E_{es.r}, E_{es.z}$ are the projections of the electrostatic field vector on the respective coordinate axes.

A qualitative electrokinetic field pattern in a particular case of motion corresponding to uniform rectilinear motion is shown in Figure 2 where the following notations are introduced: $E_{ek.r} = E_{es.r}\, v^2/(2c^2)$, $E_{ek.z} = -E_{es.z}\, v^2/(2c^2)$.

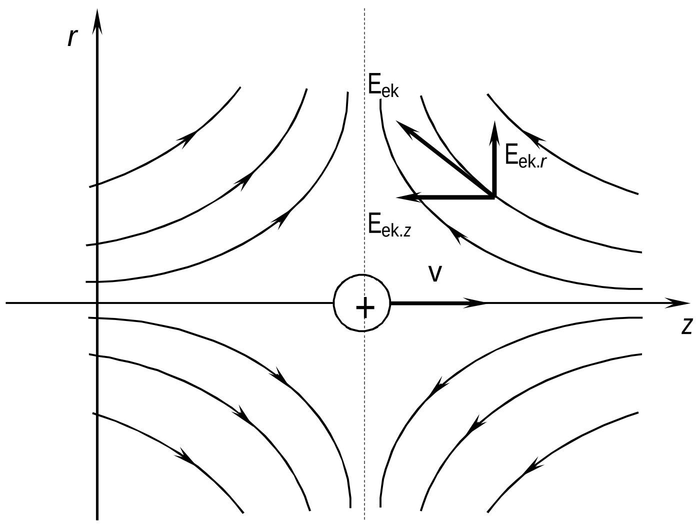


Figure 2

3.2 Electrokinetic field of a linear charge carrier

3.2.1 Electrokinetic field energy

The electrostatic field of a linear charge carrier's unit length has energy W_{es},

$$W_{es} = \frac{\lambda^2}{4\pi\varepsilon_0}\ln\frac{R_0}{R} \tag{3.8}$$

where R_0 is the radius of an equivalent source whose surface potential is taken to equal zero. In terms of the Einstein relation, the mass of this field fragment may be calculated from formula (3.9),

$$m = \frac{W_{es}}{c^2} = \frac{\lambda^2}{4\pi\varepsilon_0 c^2}\ln\frac{R_0}{R}. \tag{3.9}$$

In case of a carrier's longitudinal motion with velocity $\mathrm{v}=v_z 1_z$, the electric field as a material object comes to possess electrokinetic energy W_{ek},

$$W_{ek} \stackrel{\text{def}}{=} \frac{1}{2}mv^2 = \frac{1}{2}W_{es}\frac{v^2}{c^2} = \frac{\lambda^2}{8\pi\varepsilon_0}\frac{v^2}{c^2}\ln\frac{R_0}{R}. \tag{3.10}$$

Since we are considering a linear charge carrier that is moving in a longitudinal direction, distance R now depends only on radial coordinate r and does not depend on time.

3.2.2 Potential

Partial derivative of energy W_{ek} with respect to charge density λ reflects the electrokinetic field energy per unit charge density of a rod, i.e. determines the potential of the electrokinetic field ϕ_{ek},

$$\varphi_{ek} \stackrel{\text{def}}{=} \frac{\partial W_{ek}}{\partial\lambda} = \frac{1}{2}\varphi_{es}\frac{v^2}{c^2} = \frac{\lambda}{4\pi\varepsilon_0}\frac{v^2}{c^2}\ln\frac{R_0}{R}. \tag{3.11}$$

3.2.3 Electric current

Longitudinal motion of a linear charge carrier generates electric current. Let us define it as a quantity equal to the product of linear density λ of positive charge and speed v of the carrier's motion,

$$i \stackrel{\text{def}}{=} \lambda v. \tag{3.12}$$

Such definition does not contradict to the traditional one, $i = dQ/dt$, indeed, as, $\lambda = dQ/dl$, then

$$i = \lambda v = \frac{dQ}{dl}\frac{dl}{dt} = \frac{dQ}{dt}, \qquad (3.13)$$

instead, it specifies the scope of concept of electric current, excluding convection current from it. Besides, this definition has a definite physical meaning that coincides with the intuitive comprehension of electric current.

3.2.4 Field pulse

Partial derivative of energy W_{ek} with respect to speed v represents a pulse of a moving electric field that is created by a unit-length carrier with charge density λ,

$$\mathbf{G} \stackrel{\text{def}}{=} \frac{\partial W_{ek}}{\partial v}\mathbf{1}_{\mathbf{v}} = m\mathbf{v} = \frac{\lambda^2\mathbf{v}}{4\pi\varepsilon_0 c^2}\ln\frac{R_0}{R}. \qquad (3.14)$$

3.2.5 Inductance

The inductance of a moving linear carrier's unit of length is expressed by the mixed fourth derivative,

$$L \stackrel{\text{def}}{=} \frac{\partial^4 W_{ek}}{\partial\lambda^2\partial v^2} = \frac{1}{2\pi\varepsilon_0 c^2}\ln\frac{R_0}{R}. \qquad (3.15)$$

3.2.6 Vector potential

The mixed derivative of energy W_{ek} with respect to speed v and linear charge density λ characterizes the change in the field pulse with a unit change in charge density and speed. Let us call this quantity a vector potential A,

$$\mathbf{A} \stackrel{\text{def}}{=} \frac{\partial^2 W_{ek}}{\partial\lambda\partial v}\mathbf{1}_{\mathbf{v}} = \frac{\lambda v}{2\pi\varepsilon_0 c^2}\ln\frac{R_0}{R}\mathbf{1}_{\mathbf{v}} = \frac{i}{2\pi\varepsilon_0 c^2}\ln\frac{R_0}{R}\mathbf{1}_{\mathbf{v}} = iL\mathbf{1}_{\mathbf{v}}. \qquad (3.16)$$

3.2.7 Intensity

The electrokinetic field intensity, which is its force function, depends both on spatial change in potential ϕ_{ek}, and on the change of vector potential A with time. The electrokinetic field vector is expressed in terms of the sum, taken with the opposite sign, of electrokinetic potential gradient and the derivative of vector potential with respect to time,

$$\mathbf{E}_{ek} \stackrel{\text{def}}{=} -\left(\mathbf{grad}\varphi_{ek} + \frac{d\mathbf{A}}{dt}\right) = \frac{1}{2}E_{es}\frac{v^2}{c^2}\mathbf{1}_r - L\frac{di}{dt}\mathbf{1}_z. \qquad (3.17)$$

The second summand of the electrokinetic intensity, $L\,di/dt$, predetermines such phenomena as self-induction and mutual induction. The origin of formula (3.17) explains the physical nature of these phenomena without mentioning or resorting to the term "magnetic field".

3.2.8 Other parameters of the electrokinetic field

The quantities introduced above reflect only a part of the electrokinetic field properties. Some other derivatives still remain unconsidered that, in the event of some practical need, may acquire physical significance and the status of physical quantities.

4 Electric field of a moving charge carrier

4.1 Superposition of electrostatic and electrokinetic fields

There are only two kinds of energy subject to consideration in mechanics: firstly, it is the energy that depends on bodies' relative position, and secondly, it is the energy that is determined by the speed of one body relative to the other, which is accepted to be conditionally immovable. The first kind is potential energy, the second kind is kinetic energy. Extending this proposition to the electric field and on the basis of the above results it is natural to consider that the electric field of a moving charge carrier is the superposition of the electrostatic and the electrokinetic fields. The basic feature of the first is the presence of potential (electrostatic) energy while the second is characterized by kinetic (electrokinetic) energy.

4.2 Electric field intensity of a point charge carrier

Leaving all other field parameters out of consideration, let us dwell on the analysis of the basic force characteristic of the field: its intensity.

Intensity E of the electric field is the sum of the electrostatic (2.8) and the electrokinetic (3.7) field intensities,

$$\mathbf{E} = \mathbf{E}_{es} + \mathbf{E}_{ek} = E_{es.r}\left(1 + \frac{1}{2}\frac{v^2}{c^2}\right)\mathbf{1}_r + E_{es.z}\left(1 - \frac{1}{2}\frac{v^2}{c^2}\right)\mathbf{1}_z - \frac{\varphi_{es}a}{c^2}\mathbf{1}_z. \qquad (4.1)$$

It is interesting to note that the intensity that corresponds to the summand $\varphi_{es}a/c^2$ in formula (4.1) is the product of field mass per unit of charge φ_{es}/c^2 and acceleration *a,* which is in good agreement with Newton's second law. It should be noted, as the theory of electromagnetism denies applicability of mechanics for the analysis of electrical phenomena, and for that reason it is unable to reflect the influence of a charge carrier's motion parameters on the characteristics of its electric field.

Relation (4.1) demonstrates that compared to the electrostatic field, the intensity of the electric field in motion increases in the transverse direction (relative to the velocity vector) and decreases in the longitudinal direction. As appears from the above, the cause of it is the kinetic (electrokinetic) energy possessed by a moving electric field, not the change in linear dimensions of space, as is predetermined by the theory of relativity. Correlation of the obtained result (4.1) with the classical explanation of this phenomenon is accomplished in sub-section 5.4.

4.3 Electric field intensity of a linear charge carrier

Intensity E of the electric field is the sum of electrostatic (2.18) and electrokinetic (3.17) field intensities,

$$\mathbf{E} = \mathbf{E}_{es} + \mathbf{E}_{ek} = \mathrm{E}_{es}\left(1 + \frac{1}{2}\frac{v^2}{c^2}\right)\mathbf{1}_r - L\frac{di}{dt}\mathbf{1}_z. \tag{4.2}$$

Even in case of a charge carrier's uniform motion, the electric field intensity increases, as was found earlier, only because the field acquires kinetic energy in course of motion.

Contrary to this physically grounded explanation, some authors, for instance (4, p. 184) hold on to the opinion that the reason why the field intensity increases has to do with "excess surface charges" that are found on every conductor irrespective of whether they carry electric current or not. The opinion that there exist "excess charges" coming from no one knows where is one more postulate supporting the theory of electromagnetism at its vulnerable spot.

There is one more classical explanation (3, p. 272) based on relativistic reduction of a charge carrier's length. The obtained result (4.2) is also compared to this explanation in sub-section 5.4.

5 Theoretical grounding of the empirical relations forming the basis of electromagnetism

5.1 The nature of Ampere's law

Supposing there are two conductors with equal unidirectional currents *i*. Each conductor may be thought of as two oppositely charged linear carriers, one of which corresponds to the lattice ion core of the conductor's material while the other represents electron gas. Naturally, linear charge density at these carriers must satisfy the condition $\lambda_i = -\lambda_e$. The presence of current $i = \lambda_e v_e = -\lambda_i v_e$ in the conductors means that the negatively charged linear carrier is moving at a speed of v_e relative to the positively charged immobile carrier. Force interaction of the conductors' unit length is determined by both electrostatic and electrokinetic fields. Schematically, the effect of forces is shown in Figure 3.

Forces F_1, F_4 account for the effect of the electrostatic fields of charge carriers that are immobile relative to each other. Forces F_2, F_3 are the forces that spring up among the carriers moving relative to each other, and so they include components of both electrostatic and electrokinetic origin.

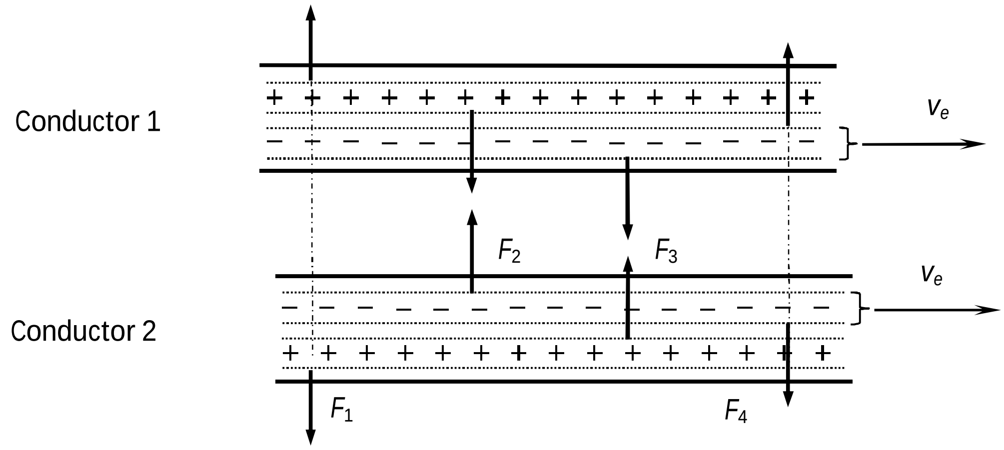


Figure 3

To determine the forces let us resort to relation (4.2) that specifies the electric field intensity of a linear charge carrier. Thus we obtain the following expressions:

$$F_1 = \lambda_i E_{es.i}, \tag{5.1}$$

$$F_2 = \lambda_e E_{es.i}\left(1 + \frac{1}{2}\frac{v^2}{c^2}\right) = -\lambda_i E_{es.i}\left(1 + \frac{1}{2}\frac{v^2}{c^2}\right), \tag{5.2}$$

$$F_3 = \lambda_i E_{es.e}\left(1 + \frac{1}{2}\frac{v^2}{c^2}\right) = -\lambda_i E_{es.i}\left(1 + \frac{1}{2}\frac{v^2}{c^2}\right), \tag{5.3}$$

$$F_4 = \lambda_e E_{es.e} = \lambda_i E_{es.i}\ . \tag{5.4}$$

The sum of these forces equals force F that acts upon the conductor's unit length in presence of unidirectional currents,

$$F = F_1 + F_2 + F_3 + F_4 = -\lambda_i E_{\text{es}.i}\frac{v^2}{c^2}\ . \tag{5.5}$$

The negative value of the force, $F < 0$, points to the fact of the conductors' mutual attraction.

The diagram illustrating the effect of forces that spring up in case of opposite currents does not differ from the one shown in Figure 3, but the direction of the carriers' velocity in conductor 2 is now reversed. It means that electrons in the conductors are moving relative to each other at a double speed, and force F_4 will be described by the following relation

$$F_4 = \lambda_e E_{es.e}\left(1 + \frac{1}{2}\frac{(2v)^2}{c^2}\right), \tag{5.6}$$

Summing up the forces, we obtain that the resultant *F* has changed in direction but retained its absolute value,

$$F = \lambda_i E_{es.i}\frac{v^2}{c^2}\,. \tag{5.7}$$

For comparison, let us determine the same force in terms of Ampere's law, which is one of the basic postulates that serve as the foundation of the theory of electricity,

$$F = \frac{\mu_0 i^2}{2\pi R} = \frac{\varepsilon_0}{\varepsilon_0}\mu_0\frac{\lambda}{2\pi R}\lambda v^2 = \lambda E\frac{v^2}{c^2}\,. \tag{5.8}$$

Since the direction of current depends on the motion of positive charge carriers, $\lambda = \lambda_i$, comparing formulas (5.5) and (5.7) with expression (5.8) we can see full agreement in their absolute values. To get the information as to a force direction, electromagnetic theory recommends using a "left-hand rule" in addition to formula (5.8). As for formulas (5.5), (5.7), in contrast to (5.8), they can give the direction of forces, not only their magnitude.

There is complete agreement in the results of theoretical and empirical (from Ampere's law) determination of interaction force between current-carrying conductors, which is the evidence of validity of the proposed theory.

Moreover, the achieved theoretical grounding of Ampere's law enables one to understand the origin of ponderomotive forces, determine their structure and explore the role of the iron core in the process of force interaction. It follows from the above that force interaction between current-carrying conductors differs essentially in the structure of forces from a similar interaction of, for instance, the electron flow in a cathode-ray tube where there are no immobile positive charge carriers.

The described mechanism of emerging Ampere's forces is much more informative than the existing explanation, which is based on such experimentally discovered phenomena as for instance, the Lorentz force or the Biot-Savart law.

5.2The nature of the Lorentz force

5.2.1 Preliminary comment

To show the nature of the Lorentz force, let us find, based on the results achieved in the previous sections of this study, the expression for the force exerted on a point charge that is moving in the vicinity of a current-carrying conductor. In terms of electromagnetism, it corresponds to a charge carrier's motion through the conductor's magnetic field. The analysis will be successively performed for different directions of a carrier's motion relative to the conductor with subsequent generalization of the obtained results.

5.2.2 The movement of a point charge carrier along the current- carrying conductor

Once more, just like in sub-section 5.1, let us imagine a conductor as a unity of two oppositely charged linear charge carriers, one of which corresponds to the ionic lattice of the conductor's material while the other represents free electrons (electron gas). Physically, the presence of electric current in a conductor signifies longitudinal motion of the second of the above mentioned carriers in relation to the first.

Assume that the motion of electrons in the conductor generates current $i = \lambda_e v_e$ where $\lambda_e < 0$ is the linear charge density of current-generating electrons, v_e= const is electron speed. Let a test charge carrier is moving along the conductor with velocity v in the direction coinciding with conventional flow. Figure 4 shows velocity directions v_e and v in dashed lines.

To determine the electric field intensity at the point of location of the test charge carrier we will switch to the coordinate system associated with this charge carrier.

In this coordinate system, the speed of the conductor's ionic lattice will be v_i, $v_i = -v$ while the speed of electrons producing current flow in the conductor will be $-(v+v_e)$.

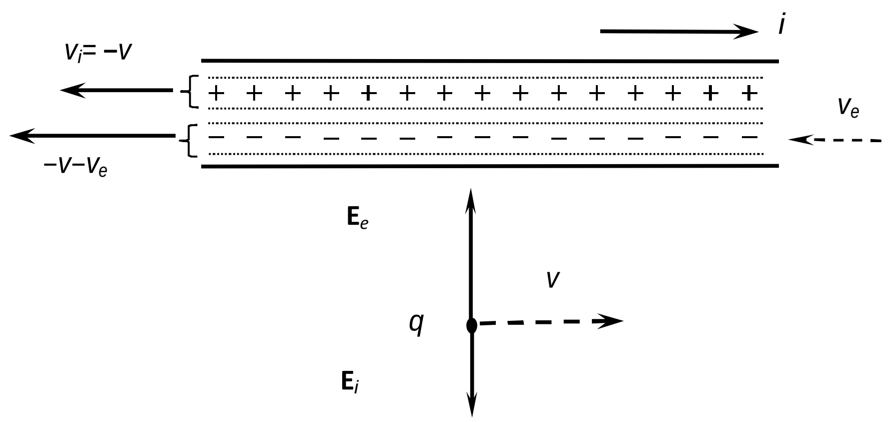


Figure 4

As follows from the above, the motion of the conductor's ionic lattice and electrons will create the respective electrokinetic fields. The resultant intensity E of the current-carrying conductor's electric field is the sum of intensity E_i of the ionic lattice field and intensity E_e of the electron field. In accordance with relation (4.2), these intensities will be expressed by formulas (5.9), (5.10),

$$E_i = E_{es.i}\left(1 + \frac{1}{2}\frac{v^2}{c^2}\right), \tag{5.9}$$

$$E_e = E_{es.e}\left(1+\frac{1}{2}\frac{\left(-(v+v_e)\right)^2}{c^2}\right) = -E_{es.i}\left(1+\frac{1}{2}\frac{\left(-(v+v_e)\right)^2}{c^2}\right). \quad (5.10)$$

This result permits finding intensity *E* of the conductor's electric field in the form of (5.11),

$$E = E_i + E_e = -\frac{1}{2}E_{es.i}\frac{v_e}{c^2}(2v+v_e). \quad (5.11)$$

In the same way, for a charge carrier's motion in a direction opposite to that of the current, we will obtain field intensity which is expressed by formula (5.12)

$$E = \frac{1}{2}E_{es.i}\frac{v_e}{c^2}(2v-v_e). \quad (5.12)$$

As follows from formula (5.12), the field vector in this case may have different directions. If $2v>v_e$ it will be directed away from the conductor, in case $2v<v_e$ its direction will change to the opposite, and at $2v=v_e$ the intensity will be equal to zero.

5.2.3 The movement of a point charge carrier in a transverse direction relative to the current-carrying conductor

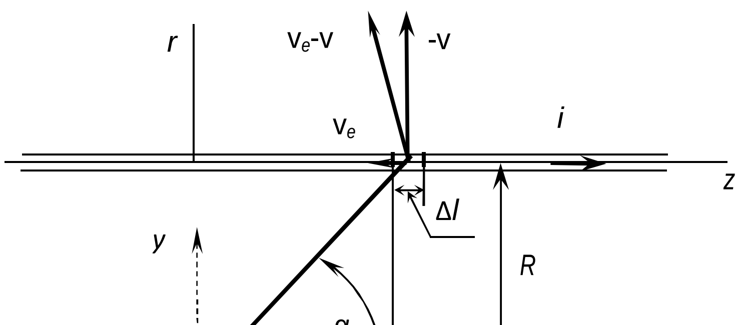
Assume that a test charge carrier is moving in the direction "away from the conductor". Let us single out some small segment Δ*l* in the conductor carrying current *i*. Figure 5 shows that in the coordinate system (*x*, *y*) associated with the charge carrier, the ionic lattice of the conductor segment Δ*l* will be moving with velocity (–v) relative to the carrier, and the velocity of current-producing electrons in segment Δ*l* will be (v_e–v).

Along with electrostatic fields, electrokinetic fields are created by moving ions and electrons of segment Δ*l* at point *A* where the test charge carrier is located. To begin with, let us consider the electrokinetic field of the carrier that corresponds to the ionic lattice (Figure 5).

As a charge carrier is moving along the *r*-axis, the projection of this field vector onto the axes of the (*r*, *z*) coordinate system will be expressed by the respective formulas:

$$\Delta E_{ek.i.r} = \Delta E_{es.i}\sin\alpha\left(1-0{,}5\frac{v^2}{c^2}\right), \quad (5.13)$$

$$\Delta E_{ek.i.z} = \Delta E_{es.i}\cos\alpha\left(1+0{,}5\frac{v^2}{c^2}\right). \quad (5.14)$$



Let us pass on to infinitesimals and integrate the obtained relations (5.13) and (5.14) with respect to the current-carrying conductor's length *l.* As a result, we will arrive at

$$E_{i.r} = \int_{-\infty}^{\infty} \frac{\lambda R}{4\pi\varepsilon_0 (R^2 + l^2)^{3/2}} \left(1 - 0{,}5\frac{v^2}{c^2}\right) dl = E_{\mathrm{es}.i} \left(1 - 0{,}5\frac{v^2}{c^2}\right), \quad (5.15)$$

$$E_{i.z} = \int_{-\infty}^{\infty} \frac{\lambda l}{4\pi\varepsilon_0 (R^2 + l^2)^{3/2}} \left(1 - 0{,}5\frac{v^2}{c^2}\right) dl = 0. \quad (5.16)$$

As seen from the obtained relations, the electrokinetic field intensity of the ironic lattice has only one radial component (5.15).

Now we will proceed to determining the electrokinetic field intensity of conduction electrons in the conductor's segment Δ*l*. Let us turn the (*x*, *y*) coordinate system so that the *x*-axis were perpendicular to the velocity vector (v_e–v), and the *y*-axis were parallel to this vector (Figure 6). This allows the expressions to be written for projections of the electrons' electric field intensity onto the (*x*, *y*) coordinate axes,

$$\Delta E_{e.x} = \Delta E_{es.e} \cos(\alpha - \beta) \left(1 + 0{,}5\frac{v_e^2 + v^2}{c^2}\right). \quad (5.17)$$

$$\Delta E_{e.y} = \Delta E_{es.e} \sin(\alpha - \beta) \left(1 - 0{,}5\frac{v_e^2 + v^2}{c^2}\right). \quad (5.18)$$

Let us find the projections of quantities (5.17) and (5.18) onto the (*r*, *z*) coordinate axes,

$$\Delta E_{e.r} = \Delta E_{e.y} \cos\beta + \Delta E_{e.x} \sin\beta\ , \quad (5.19)$$

$$\Delta E_{e.z} = -\Delta E_{e.y} \sin\beta + \Delta E_{e.x} \cos\beta\ . \quad (5.20)$$

In the latter formulas angle β is a constant, $\beta = \mathrm{arctg}(v_e/v)$, and the trigonometric functions of angle α are expressed through the lengths of the corresponding segments. Having substituted these quantities and after passing on to infinitesimals we will integrate relations (5.19) and (5.20) for *l* going from – ∞ to + ∞. We will obtain that the projections of the vector of the electric field created by electrons at the observation point are expressed by formulas (5.21), (5.22),

$$E_{e.r} = E_{es.e}\left(1 - 0{,}5\frac{v^2}{c^2} + 0{,}5\frac{v_e^2}{c^2}\right) = -E_{es.i}\left(1 - 0{,}5\frac{v^2}{c^2} + 0{,}5\frac{v_e^2}{c^2}\right), \quad (5.21)$$

$$E_{e.z} = E_{es.e}\frac{v_e\,v}{c^2} = -\,E_{es.i}\frac{v_e\,v}{c^2}\,. \quad (5.22)$$

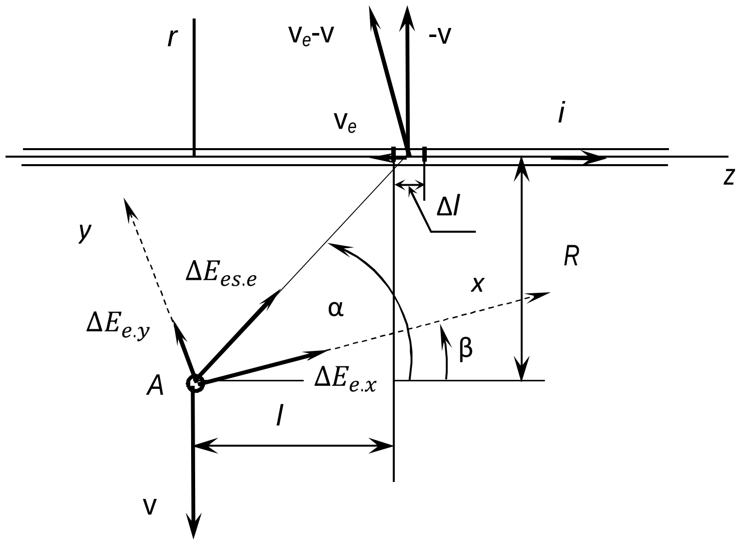


Figure 6

The radial projection of the electric field vector is the sum of the ion field (5.15) and the electron field (5.21) intensities,

$$E_r = E_{i.r} + E_{e.r} = -\frac{1}{2}E_{es.i}\frac{v_e^2}{c^2}\,. \quad (5.23)$$

In the direction of the *z*-axis, the component of the ion field intensity equals zero, therefore in this direction the intensity is only determined by the electron field intensity (5.22),

$$E_z = E_{e.z} = -E_{es.i}\frac{v_e v}{c^2}. \quad (5.24)$$

Formulas (5.23) and (5.24) express the components of intensity of the electric field that is created when a charge carrier is moving away from the conductor. In the same way, analyzing field intensity in case of a test charge carrier’s movement towards the conductor, we will obtain that the radial component remains unchanged while the component along the *z*-axis reverses its sign because so does speed *v*,

$$E_r = -\frac{1}{2}E_{es.i}\frac{v_e^2}{c^2}\,, \quad (5.25)$$

$$E_z = E_{es.i}\frac{v_e v}{c^2}. \quad (5.26)$$

All relations that account for the intensity of the field acting upon a test charge carrier in different types of its movement relative to the current-carrying conductor, that is (5.11) for a test carrier's movement in the direction coinciding with conventional flow, (5.12) for the opposite-to-current direction, (5.23), (5.24) for movement away from the current-carrying conductor and (5.25), (5.26) for movement towards the conductor may be written as one vector formula (5.27),

$$\mathbf{E} = -(\mathbf{v} - 0{,}5\,\mathbf{v}_e) \times (\mathbf{v}_e \times \mathbf{E}_{\mathrm{es}.i})c^{-2}. \quad (5.27)$$

It will be remembered that intensity (5.27) was determined in terms of the coordinate system associated with a test charge carrier, therefore the force acting upon this carrier is the product of this intensity by the amount of test charge q,

$$\mathbf{F} = q\mathbf{E} = -q(\mathbf{v} - 0{,}5\,\mathbf{v}_e) \times (\mathbf{v}_e \times \mathbf{E}_{\mathrm{es}.i})c^{-2}, \quad (5.28)$$

5.2.4 The Lorentz force

In accordance with the theory of electromagnetism, longitudinal motion of a positively charged linear charge carrier creates a magnetic field with induction $\mathbf{B} = c^{-2}\mathbf{v} \times \mathbf{E}$, where v is velocity vector, E is the charge carrier's electric-field vector. Applying this proposition to vector product $-c^{-2}(\mathbf{v}_e \times \mathbf{E}_{\mathrm{es}.i})$ in formula (5.27), considering that $\mathbf{v} = -\mathbf{v}_e$, then this formula may be recast in the form of (5.29),

$$\mathbf{E} = (\mathbf{v} - 0{,}5\mathbf{v}_e) \times \mathbf{B}\,. \quad (5.29)$$

Hence it follows that the force acting upon test charge carrier q is expressed by relation (5.30),

$$\mathbf{F} = q\mathbf{E} = q(\mathbf{v} - 0{,}5\mathbf{v}_e) \times \mathbf{B}\,. \quad (5.30)$$

Formula (5.28) and its transformation by using the concept of magnetic induction (5.30) is the most general expression of the Lorentz force, resulting in some particular cases.

Firstly, when the speed of carrier of charge q is much more than the electron speed, $|v| \gg |v_e|$, the second summand may be disregarded, and relation (5.30) turns into the classical formula of the Lorentz force:

$$\mathbf{F} = -q\mathbf{v} \times (\mathbf{v}_e \times \mathbf{E}_{es.i})c^{-2}q\mathbf{E} = q\mathbf{v} \times \mathbf{B}\,. \quad (5.31)$$

Secondly, in absence of a charge carrier's motion relative to the current-carrying conductor, i.e. at $v = 0$, nevertheless, it will be acted upon by a force (5.32),

$$\mathbf{F} = 0{,}5q\mathbf{v}_e \times (\mathbf{v}_e \times \mathbf{E}_{es.i})c^{-2} = -0{,}5\,q\,\mathbf{v}_e \times \mathbf{B}. \quad (5.32)$$

This conclusion disproves a deeply rooted opinion that “a charge at rest is not affected by the magnetic field”. Just because the force is so small it has not yet been discovered in an experiment.

Thirdly, when a charge carrier’s velocity and electron velocity in the conductor coincide in direction, force F may have different directions or may be equal to zero depending on the sign and the value of the sum in brackets of formula (5.28). If the carrier’s motion is in a reverse direction relative to the electron velocity, than given any correlation of absolute values of speeds v and v_e, force F cannot change the direction or become equal to zero.

The accomplished analysis of the nature of the Lorentz force demonstrates that the generalization of experimental data in the form of $\mathbf{F} = q\mathbf{v} \times \mathbf{B}$ serving the basis for electromagnetic theory is a much poorer representation of the physical phenomenon as compared to the above theoretical investigation into the issue that has resulted in relation (5.28).

5.3 The nature of the law of electromagnetic induction

5.3.1 Emf generated with the conductor’s motion in a constant magnetic field

Our investigation will be conducted by means of a construction frequently mentioned in textbooks featuring a loop with a movable bar (Figure 7) that is placed in a magnetic field of a rectilinear conductor containing current $i = \lambda_e v_e$ where λ_e is the linear density of free charge carriers (electrons), v_e is the speed of these carriers. Let us place the cylindrical coordinate system (r, θ,z) so that the z-axis coincide with the longitudinal axis of a current-carrying conductor.

Item 5.2.3 shows that when a charge carrier is moving in a transverse direction relative to the current-carrying conductor, it is affected by an electric field whose intensity projections are expressed by formulas (5.23), (5.24). To calculate the value of the emf generated with the bar motion at a speed of v it will suffice to multiply these projections by diameter d and by the bar length l respectively. As a result, we obtain emf in a transverse direction of the bar (5.33),

$$\mathcal{E}_r = -\frac{1}{2} E_{\mathrm{es}.i} \frac{v_e^2}{c^2} d, \tag{5.33}$$

and emf in a longitudinal direction of the bar (5.34),

$$\mathcal{E}_z = -E_{\mathrm{es}.i} \frac{v_e v}{\mathrm{c}^2} l = E_{\mathrm{es}.i} \frac{v_i v}{\mathrm{c}^2} l. \tag{5.34}$$

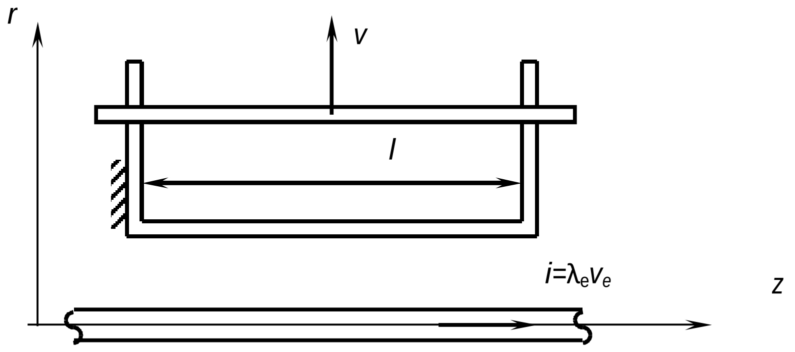


Figure 7

Due to a slow speed of electrons in the conductor, emf (5.33) has not yet found its experimental confirmation, to say nothing of a technical application. Longitudinal emf (5.34) is fully in keeping with the emf that is spoken of in the law of electromagnetic induction. Indeed, considering that the direction of the normal to the surface of the circuit is pointed towards us and having substituted the expression of electrostatic intensity $E_{\mathrm{es}.i}$ into relation (5.34) we obtain

$$\mathcal{E}_z = -E_{es.i}\frac{v_i v}{c^2}l = -\frac{\lambda_i v_i}{2\pi\varepsilon_0 R c^2}vl = -Bvl, \qquad (5.35)$$

where *B* is the induction of the current-carrying conductor's magnetic field.

Formula (5.35) is in complete agreement with the classical expression of emf induced in a moving conductor, but it has been derived irrespective of any empirical postulates, resulting from a pure theoretical analysis.

5.3.2 Emf in a circuit placed in a changing magnetic field

Assume there is a conductor with a linearly increasing current $i = \lambda_i v_i$ where $v_i = v_0 + at$. Let us place loop ABCD near the conductor (Figure 8).

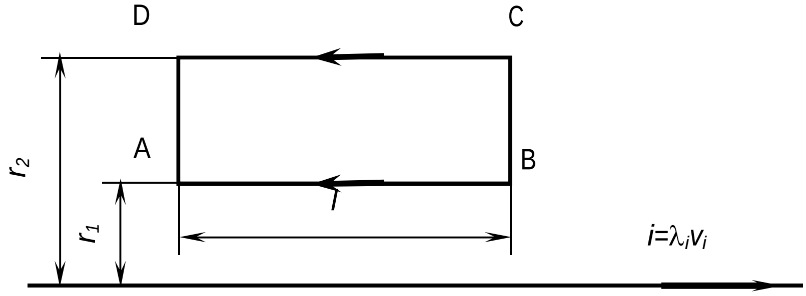


Figure 8

To determine the emf that is generated in the loop let us resort to relation (3.17), whereby in the vicinity of a linear charge carrier that is in accelerated motion the electrokinetic field is created whose intensity is

$$\mathbf{E}_{ek} = \frac{1}{2}E_{es}\frac{v^2}{c^2}\mathbf{1}_r - L\frac{di}{dt}\mathbf{1}_z = \frac{1}{2}E_{es}\frac{v^2}{c^2}\mathbf{1}_r - \frac{\lambda_i \mathbf{a}_i}{2\pi\varepsilon_0 c^2}\ln\frac{R_0}{R}\mathbf{1}_z. \quad (5.36)$$

The field vector represented in this expression by the first summand has a radial direction and thus initiates equal and unidirectional emfs in the loop sides AD and BC.

Loop sides AB and CD are parallel to the conductor, therefore emf will be generated in them that is caused by the second summand of the expression (5.36). The electrokinetic field intensities in these sides will be expressed by relations (5.37) and (5.38),

$$\mathbf{E}_{ek}^{AB} = -\frac{\lambda_i \mathbf{a}_i}{2\pi\varepsilon_0 c^2}\ln\frac{R_0}{r_1}, \quad (5.37)$$

$$\mathbf{E}_{ek}^{CD} = -\frac{\lambda_i \mathbf{a}_i}{2\pi\varepsilon_0 c^2}\ln\frac{R_0}{r_2}. \quad (5.38)$$

Multiplying now the obtained intensities by the lengths of the sides, we will get the induced emfs. Electromotive force $\mathcal{E}$ that is generated throughout the loop will be found by summing up the emfs of the sides in accordance with Kirchhoff's second law. The contribution of sides AD and BC to the sum of emfs will be zero, therefore we obtain

$$\mathcal{E} = l(E_{ek}^{AB} - E_{ek}^{CD}) = -\frac{\lambda a l}{2\pi\varepsilon_0 c^2}\ln\frac{r_2}{r_1}. \quad (5.39)$$

It is easily ascertained that this result matches emf $\mathcal{E} = -d\Phi/dt$ that can be derived from Faraday's law.

Indeed, induction B of a magnetic field around a conductor with a linearly increasing current is expressed by formula (5.40),

$$B = \frac{\lambda}{2\pi\varepsilon_0 c^2 r}a\left(t - \frac{r}{c}\right). \quad (5.40)$$

Magnetic flux through a surface element of length l and width Δr will make $\Delta\Phi = B\Delta rl$. Integrating this expression over r from r_1 to r_2, we will obtain magnetic flux Φ through the whole loop ABCD,

$$\Phi = \int_{r_1}^{r_2} Bldr = \frac{\lambda lat}{2\pi\varepsilon_0 c^2}\ln\frac{r_2}{r_1} - \frac{\lambda la}{2\pi\varepsilon_0 c^3}(r_2 - r_1)\ . \qquad (5.41)$$

Now taking the derivative of flux Φ with respect to time, we will arrive at the desired expression for electromotive force,

$$\mathcal{E} = -\frac{d\Phi}{dt} = -\frac{\lambda al}{2\pi\varepsilon_0 c^2}\ln\frac{r_2}{r_1}\ . \qquad (5.42)$$

The obtained relation (5.42) fully coincides with expression (5.39). They differ in that formula (5.39) has been derived relying on the above introduced basic concepts of the systematic theory of electrical phenomena whereas expression (5.42) has no theoretical grounding, being just a generalization of experimental data accomplished by Michael Faraday.

5.4 Lorentz transformations

Contemporary electromagnetic theory provides a rather formal explanation of the change in the electric field intensity in course of a charge carrier's motion, making references to the effects of a special theory of relativity (STR). It is agreed that the change in intensity under these conditions is subject to the Lorentz transformations, but none the less, there seems to be no concern about the reason why the intensity should be subject to these mathematical transformations.

The classical solution of the problem about the field intensity of a point charge which is in uniform motion at the moment when the charge carrier is passing through the origin, is given in textbook (4, p. 238). In accordance with this solution, the intensity should be expressed by formula (5.43),

$$\mathbf{E}_{cl} = E_{es.r}\frac{1-(v/c)^2}{(1-(v/c)^2\sin^2\alpha)^{3/2}}\mathbf{1}_r + E_{es.z}\frac{1-(v/c)^2}{(1-(v/c)^2\sin^2\alpha)^{3/2}}\mathbf{1}_z, \qquad (5.43)$$

where α is the angle between the vector of the carrier's velocity v and the radius vector R of the observation point relative to the charge carrier (see Figure 1).

Based on the systematic theory of electrical phenomena that is presented here, formula (5.44) will be true for the carrier's uniform motion, which can be derived from relation (4.1), putting acceleration equal to zero, $a = 0$,

$$\mathbf{E} = E_{es.r}\left(1 + \frac{1}{2}\frac{v^2}{c^2}\right)\mathbf{1}_r + E_{es.z}\left(1 - \frac{1}{2}\frac{v^2}{c^2}\right)\mathbf{1}_z. \qquad (5.44)$$

Qualitatively, formula (5.44) differs from expression (5.43) in that intensity (5.44) does not depend on the angle α. In order to discover a quantitative difference, let us make a comparison of intensities predicted by relations (5.43) and (5.44), taking three values of this angle: α = 0, α = π/2, α = π/4.

At α = 0 intensity (5.43) has only one component along the *z*-axis, that takes the form of

$$E_{cl}|_{\alpha=0} = E_{es.z}(1 - (v/c)^2), \qquad (5.45)$$

while from (5.44) follows

$$E|_{\alpha=0} = E_{es.z}(1 - (v/c)^2/2). \qquad (5.46)$$

At α = π/2 the respective intensities are expressed by formulas (5.47) and (5.48),

$$E_{cl}|_{\alpha=\pi/2} = E_{es.r}(1 - (v/c)^2)^{-1/2}, \qquad (5.47)$$

$$E|_{\alpha=\pi/2} = E_{es.r}(1 + (v/c)^2/2). \qquad (5.48)$$

At α = π/4 the relations assume the following form:

$$E_{cl}|_{\alpha=\pi/4} = E_{es}\frac{\sqrt{8}\,(1 - (v/c)^2)}{(2 - (v/c)^2)^{3/2}}, \qquad (5.49)$$

$$E|_{\alpha=\pi/4} = E_{es}(1 + (v/c)^4/4)^{1/2}. \qquad (5.50)$$

Let us compare the quantities by analyzing the graphs of intensity ratios $E_{cl}|_\alpha/E|_\alpha$ for each value of angle α at changing speed *v* in the range of $0 < v < 2 \cdot 10^8$ m/s. The respective graphs are shown in Figure 9.

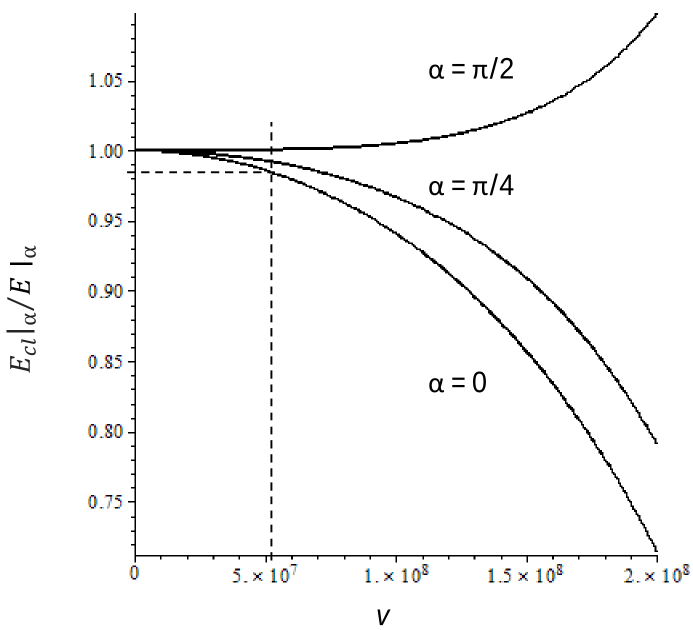


Figure 9

The analysis of the graphs shows that at speeds available for experimental verification, the ratio between the intensity calculated from the classical formula and the intensity found by means of STEP virtually does not differ from a unity. The difference increases with increasing speed, but even at a speed of $v \approx 0{,}5 \cdot 10^8$ m/s it makes up no more than one and a half percent. As the speed approaches the speed of light, the difference in intensity values becomes more pronounced, but it is significant that STEP does not result in infinitely large values of intensity at $v = c$, which means that it imposes no limitations on reaching or even exceeding the speed of light.

The same results follow from the comparison of intensities in case of a linear charge carrier.

To date, there is no experimental data on the range of speeds close to the speed of light, which could have guided us in preferring one of the correlated theories. Nevertheless, the formal origin of the expression (5.43) and the physically grounded derivation of relation (5.44) allow doubts in the validity of a classical viewpoint that is based solely on the belief in the applicability of the Lorentz transformations to physical processes.

The above theoretical explanation of the dependence of field intensity on the speed is based only on admitting the fact that the electrostatic field is a material substance that acquires kinetic energy when in motion. All other logical corollaries of these propositions cannot be challenged as being purely mathematical constructs.

6 Solution of problems unsolved in the theory of electromagnetism

6.1Force interaction of point charge carriers

6.1.1 Interaction in case of motion in mutually perpendicular directions

Interaction of point charges in case of their motion in perpendicular directions is described in terms of the theory of electromagnetism in textbooks (18, p. 212), (19, p. 208) as well as in a number of other books. The authors of all these works insist that in case of such interaction, one of the fundamental propositions in physics – the principle of equality of action and reaction – becomes invalid. For instance, textbook (18, p. 214) says in this respect: "…time and again, we have pointed out that in case of interactions by means of fields, the principle of equality of action and reaction is not necessarily observed."

As a matter of fact, such a conclusion is certainly erroneous. It is just that failing to explain the mechanism of interaction in terms of the accepted classical paradigm the authors resorted to an easier way of inventing a new postulate that has canonized contradiction to Newton's law. The analysis of interaction forces between charge carriers presented hereunder refutes the opinion of the above sources and shows that in this case, too, action equals reaction.

Assume there are two charge carriers in uniform motion, whose position and velocities are shown in Figure 10a. The problem is that charge carrier № 1 is within the magnetic field of charge carrier № 2, and consequently, it is affected by some nonzero force. At the same time, charge carrier № 2 is in one of the special points of the magnetic field created by charge carrier № 1, and in accordance with the theory of electromagnetism, the force exerted upon it should be equal to zero. Obviously, Newton's third law is violated.

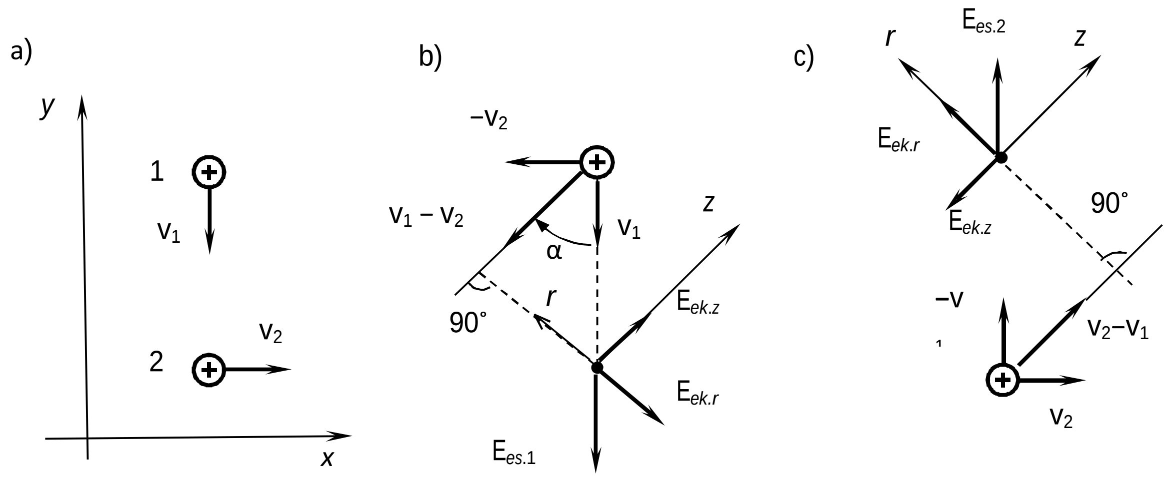


Figure 10

Let us perform the analysis of forces acting upon the charge carriers using the above described STEP.

To determine the electric field intensity of charge carrier № 1 at the point where charge carrier № 2 is located, let us go over to the coordinate system (*r*, *z*), that is moving along with it (Figure 10b). In this coordinate system, charge carrier № 1 has velocity v_1-v_2, which means that the intensity of its electric field at the second carrier's point of location will be determined by relation (3.7) where it should be put $v^2 = v_1^2 + v_2^2$. In order to use formula (3.7), let us turn the axes of the coordinate system (*r*, *z*) so that the *z*-axis is parallel and the *r*-axis perpendicular to velocity v_1-v_2. As a result, we will arrive at the intensity expressed in terms of the coordinate system (*r*, *z*),

$$\mathbf{E}_{12}^{rz} = E_{es.1}\sin\alpha\left(1+\frac{v_1^2+v_2^2}{2c^2}\right)\mathbf{1}_r + E_{es.1}\cos\alpha\left(1-\frac{v_1^2+v_2^2}{2c^2}\right)\mathbf{1}_z, \qquad (6.1)$$

where $\alpha = \text{arc tg}(-v_2/v_1)$.

In the coordinate system (x, y), the vector of the field created by the first carrier at the point of the second carrier's location, is determined by the projections of vector components (6.1) onto this system's axes,

$$\mathbf{E}_{12}^{xy} = E_{es.1}\sin 2\alpha\frac{v_1^2+v_2^2}{2c^2}\mathbf{1}_x - E_{es.1}\left(1-\cos 2\alpha\frac{v_1^2+v_2^2}{2c^2}\right)\mathbf{1}_y\,. \qquad (6.2)$$

To determine the electric field intensity of the second charge carrier at the point of the first carrier's location (Figure 10c), similar constructions and calculations should be made. It will help us find the field intensity vector $\mathbf{E}_{21}^{xy}$ as follows:

$$\mathbf{E}_{21}^{xy} = -E_{es.2}\sin 2\alpha\frac{v_1^2+v_2^2}{2c^2}\mathbf{1}_x + E_{es.2}\left(1-\cos 2\alpha\frac{v_1^2+v_2^2}{2c^2}\right)\mathbf{1}_y, \qquad (6.3)$$

where $E_{es.2}$ is the electrostatic field intensity of the second carrier at the point of the first carrier's location.

Knowing intensities (6.2) and (6.3), it is not difficult to determine the forces acting upon the charge carriers. The second carrier with charge Q_2 is acted upon by force F_{12} from the first carrier with charge Q_1,

$$\mathbf{F}_{12} = Q_2\mathbf{E}_{12}^{xy} = \frac{Q_2Q_1}{4\pi\varepsilon_0R^2}\left(\sin 2\alpha\frac{v_1^2+v_2^2}{2c^2}\mathbf{1}_x - \left(1-\cos 2\alpha\frac{v_1^2+v_2^2}{2c^2}\right)\mathbf{1}_y\right), \qquad (6.4)$$

while the first carrier is experiencing force F_{21} coming from the second carrier,

$$\mathbf{F}_{21} = Q_1\mathbf{E}_{21}^{xy} = \frac{Q_2Q_1}{4\pi\varepsilon_0R^2}\left(-\sin 2\alpha\frac{v_1^2+v_2^2}{2c^2}\mathbf{1}_x + \left(1-\cos 2\alpha\frac{v_1^2+v_2^2}{2c^2}\right)\mathbf{1}_y\right). \qquad (6.5)$$

It is seen from the comparison of expressions (6.4), (6.5) that components $F_{12.y}$ and $F_{21.y}$ of decomposition of vectors F_{12} and F_{21} along the coordinate axes are equal in modulus, opposite in direction and have a common line of action. These components provide central character of force interaction in full compliance with the requirements of Newton's third law.

Components $F_{12.x}$ and $F_{21.x}$ of vectors along the *x*-axis are also equal in modulus and opposite in direction, $\mathbf{F}_{12.x} = -\mathbf{F}_{21.x}$, but their lines of action are parallel, not identical. These forces create equal but opposite moments (Figure 11).

Force $F_{12.x}$ acting upon the second charge carrier creates moment $\mathbf{M}_{12}$ relative to the first carrier's point of location,

$$\mathbf{M}_{12} = \mathbf{h} \times \mathbf{F}_{12.x}, \tag{6.6}$$

where h is a vector that is equal in modulus to the distance between the charge carriers and that is directed from the first carrier's point of location to the second carrier's point of location.

Force $F_{21.x}$ acting upon the first charge carrier creates moment $\mathbf{M}_{21}$ relative to the second carrier's point of location,

$$\mathbf{M}_{21} = -\mathbf{h} \times \mathbf{F}_{21.x}. \tag{6.7}$$

As shown in Figure 11, considering that $\mathbf{F}_{12.x} = -\mathbf{F}_{21.x}$, moment (6.7) may be

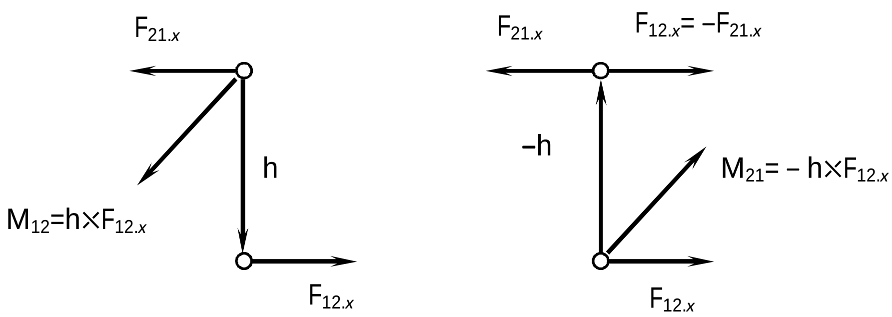


Figure 11

expressed through force $\mathbf{F}_{12.x}$,

$$\mathbf{M}_{21} = -\mathbf{h} \times \mathbf{F}_{12.x}\,. \tag{6.8}$$

It is seen from the comparison of moments (6.6) and (6.8) that they are equal but opposite, which corresponds to the proposition "action is equal to reaction".

Thus, Newton's third law is not violated, but the notions of "action" and "reaction" should include not only forces but also moments that are created when the bodies interacting by means of fields approach each other.

6.1.2 Interaction in case of motion in parallel directions

Many sources, for instance (4, pp. 157, 239), (18, p. 213) state that force interaction of charge carriers moving in parallel directions is composed of the electrical interaction (Coulomb's law) and magnetic interaction that occurs because one of the carriers is within the other carrier's magnetic field.

Despite this opinion based on the postulates of the theory of electromagnetism, let us show that the interaction of charge carriers moving with the same speed in the same direction is no different from electrostatic interaction. First of all, let us determine the electric field intensity of charge carrier № 1 at a point of location of charge carrier № 2. This can be done by using relation (4.1) where speed v should be put equal to the speed of the carriers' relative motion, $v = v_1 - v_2$,

$$\mathbf{E}_{12} = E_{es.1.r}\left(1 + \frac{1}{2}\frac{(v_1 - v_2)^2}{c^2}\right)\mathbf{1}_r + E_{es.1.z}\left(1 - \frac{1}{2}\frac{(v_1 - v_2)^2}{c^2}\right)\mathbf{1}_z. \quad (6.9)$$

In the same way, let us find the electric field intensity of charge carrier №2 at a point of location of charge carrier № 1,

$$\mathbf{E}_{21} = E_{es.2.r}\left(1 + \frac{1}{2}\frac{(v_1 - v_2)^2}{c^2}\right)\mathbf{1}_r + E_{es.2.z}\left(1 - \frac{1}{2}\frac{(v_1 - v_2)^2}{c^2}\right)\mathbf{1}_z . \quad (6.10)$$

The carriers' interaction forces can now be determined multiplying intensities (6.9) and (6.10) by the respective charges. The second carrier is acted upon by force (6.11) from the first carrier,

$$\mathbf{F}_{12} = Q_2E_{es.1.r}\left(1 + \frac{1}{2}\frac{(v_1 - v_2)^2}{c^2}\right)\mathbf{1}_r + Q_2E_{es.1.z}\left(1 - \frac{1}{2}\frac{(v_1 - v_2)^2}{c^2}\right)\mathbf{1}_z, \quad (6.11)$$

and the first is acted upon by force (6.12) from the second,

$$\mathbf{F}_{21} = Q_1E_{es.2.r}\left(1 + \frac{1}{2}\frac{(v_1 - v_2)^2}{c^2}\right)\mathbf{1}_r + Q_1E_{es.2.z}\left(1 - \frac{1}{2}\frac{(v_1 - v_2)^2}{c^2}\right)\mathbf{1}_z . \quad (6.12)$$

It follows from the above formulas that in a particular case of motion when the carriers' speeds are the same, $v_1 = v_2$, the forces are equal to electrostatic interaction forces that can be calculated from Coulomb's law.

This conclusion should also be made from the following considerations. If we change over to the coordinate system that is moving with velocity v along with the charge carriers, $v = v_1 = v_2$, then the charge carriers will be immovable both with respect to one another and to the observer. Hence it follows that there cannot be any magnetic components of interaction forces, interaction in this case is described by the laws of electrostatics alone.

6.2Emission in case of accelerated charge carrier's motion

It is assumed, for instance (5, p. 95), (14, p. 145) that any accelerated motion is accompanied by emission of electromagnetic waves. It follows from this proposition that an electron traveling around the atom's nucleus should inevitably be losing energy. As a consequence, the problem of atomic stability arises that was solved by N. Bohr in quite a peculiar manner. Conforming to reality but contrary to classical electrodynamics, he has postulated that in certain states (in certain orbits) the electron does not emit electromagnetic waves. The development of science went along the lines prescribed by

Bohr, but another problem cropped up – the problem of adequacy of electromagnetic theory that until now is unable to answer the question why there is no emission in these states (in these orbits).

The best way to find out the conditions when a moving charge carrier becomes the source of energy emission is to analyze the change in its electric field energy with time. In the case when the energy changes, emission undoubtedly takes place; but if the energy does not change, it is an irrefutable evidence that there is no emission.

Energy W of the charge carrier's electric field is the sum of electrostatic W_{es} (2.4) and electrokinetic W_{ek} (3.3) energies,

$$W = W_{es} + W_{ek} \,. \tag{6.13}$$

Let a charge carrier be moving in a circle with radius R, then considering that $v^2 = \mathbf{v} \cdot \mathbf{v}$, the derivative of energy W with respect to time t will take the form of:

$$\frac{dW}{dt} = \frac{dW_{ek}}{dt} = \frac{Q^2}{8\pi\varepsilon_0 R c^2} \mathbf{a} \cdot \mathbf{v} \,. \tag{6.14}$$

Formula (6.14) allows for a rather important conclusion: a charge carrier in an accelerated motion emits energy only when the scalar product of acceleration vector **a** and velocity vector v is nonzero, $\mathbf{a} \cdot \mathbf{v} \neq 0$. If a charge carrier is moving in a circle at a constant circular velocity, then the condition $\mathbf{a} \cdot \mathbf{v} = 0$ is always met, therefore it does not emit in spite of centripetal acceleration. Thus, to explain atomic stability there is no need to resort neither to Bohr's postulates nor to the results of quantum mechanics.

Bohr's postulate should be substituted by a well-grounded conclusion: an electron that is uniformly traveling around the atom's nucleus does not emit electromagnetic energy if its orbit is a circle.

6.3 Transfer of energy. The Poynting vector.

The electric field that is moving along with a charge carrier relative to an observer creates associated (with the field) energy flux S that must equal the product of electrostatic field energy density w_{es} by velocity v. Energy density of a linear charge carrier's electrostatic field w_{es} was determined above by expression (2.23) from which we obtain

$$\mathbf{S} = w_{es}\mathbf{v} = \frac{\lambda^2}{8\pi^2\varepsilon_0 R^2}\mathbf{v}. \tag{6.15}$$

Rendered in terms of electromagnetic theory, formula (6.15) takes the following form:

$$\mathbf{S} = \frac{\lambda^2}{8\pi^2\varepsilon_0 R^2}\mathbf{v} = \frac{1}{2}\mathbf{E}\times(\mathbf{v}\times\mathbf{D}) = \frac{1}{2}\mathbf{E}\times\mathbf{H}, \qquad (6.16)$$

where E, H are electric and magnetic field vectors respectively.

The resulting energy flux has turned out to be half as much as the flux predicted by the Poynting vector. Such a discrepancy seems to be caused by the substitution of a real electric field by an imaginary electromagnetic field. Sticking to the concept of the electromagnetic field, field energy density is erroneously taken to be the sum of energy densities of electrostatic and magnetic fields. As a matter of fact, the magnetic field is in no way involved in transfer of energy, being just a sign of electric field motion. It is the electric field as a material object that is capable of motion and energy transfer.

Here is an analogy, if not a very good one: the wind is just a sign of the fact that there is air flow at a certain point in space, and consequently, there is transfer of associated (with air) potential energy. Wind as such is a phenomenon (immaterial object) that qualitatively represents the state of motion of air (material object) relative to the observer. In physics, the concept of motion is only applicable to material objects, not phenomena, provided the use is not figurative, as for instance in the expression “movement of thought”. But this is not concerned with physics. Just like the wind, the magnetic field is not a material substance. It merely reflects the existence of a moving electric field, which is doubtlessly a material medium.

Furthermore, formula (6.16) testifies that the vector product of $\mathbf{E}\times\mathbf{H}$ accounts for energy flux only in case when these vectors belong to one and the same moving electric field. Incomprehension of this gave birth to “…a seemingly empty idea of ceaseless circulation of energy in closed paths within a static electromagnetic field” (19, p. 435). The same viewpoint is held by the author (17, p. 45). If the word “seemingly” is removed from this quotation, the latter will be quite to the point. Indeed, this idea is empty as it considers superimposition of some electrostatic field on a totally unrelated field of a permanent magnet. In this situation, one may be looking for energy flux only on the ground of implicit belief in the dogma expressed by the Poynting formula. And belief has never been a scientific method.

6.4Solution of electromagnetic paradox

One more issue unresolved in terms of classical theory is a problem that is known from the last mid-century as a certain “electromagnetic paradox”(13). The task is to take the readings of a voltmeter connected to brushes that are immobile relative to an observer, provided that there is a conductor carrying constant current *i* that is placed along the axis of a moving cylinder made of conducting material. A diagram illustrating the problem situation is shown in Figure 12.

In spite of the fact that the magnetic permeability of cylinder wall material has a considerable effect on the magnitude of magnetic flux running through the measuring loop, it has been found experimentally that the voltmeter readings do not depend on the magnetic properties of this material. This is what makes the phenomenon paradoxical.

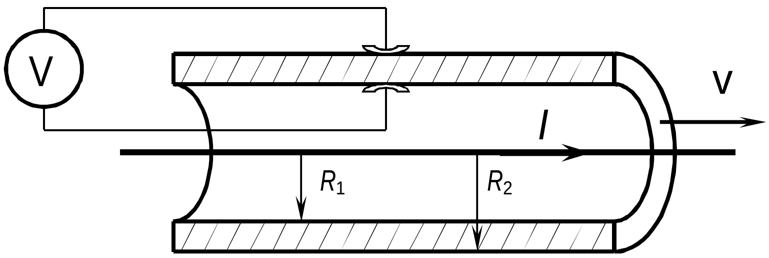


Figure 12

Statement of the problem and its solution are presented in the book (12, p. 96). The solution is described on three pages of a serious mathematical text that resorts to such terms as “vortex field component”, “apparent polarization”, “electromagnetic induction”, “vector potential” etc. As a result, a solution is obtained in the form of expression (6.17) that accounts for the fact that the voltage U registered by the voltmeter is independent of the properties of the cylinder wall material.

$$U = i\frac{v\mu_0}{2\pi}\ln\frac{R_1}{R_2}. \tag{6.17}$$

The summary following the solution says: “The structure of the field that was easily (on three pages! – M.K.) determined from the relations of relativistic electrodynamics is not so easily explored by means of pre-relativistic theories.” Let us try to disprove this viewpoint.

To solve the problem by means of the suggested systematic theory of electrical phenomena, let us change over to the system of coordinates where the cylinder is an immobile body. Let us imagine the current-carrying conductor to be a model consisting of two linear charge carriers. The scheme of the problem is now transformed into a model representation shown in Figure 13.

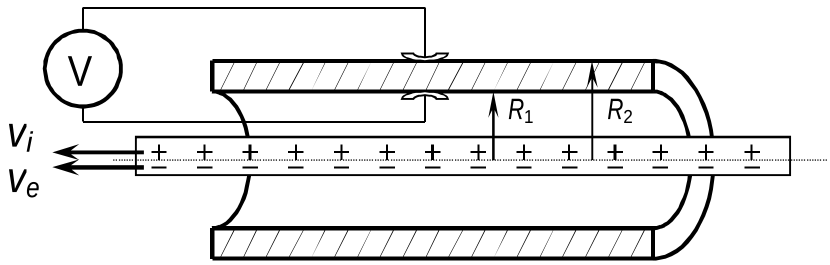


Figure13

At the accepted assumption of the cylinder’s immobility, the speed of a linear negative charge carrier will be $v_e = -v + i/\lambda_e$, where $\lambda_e < 0$ is linear density of the negative charge. The speed of a positive charge carrier relative to the cylinder will be $v_i = -v$

The potential of the cylinder's outer surface will be considered to equal zero. Using relations (2.16) and (3.11), let us find the electric field potentials for each of the above mentioned charge carriers at distance R_1, i.e. at the cylinder's inner surface.

$$\varphi_i = \varphi_{es.i} + \varphi_{ek.i} = \frac{\lambda_i}{2\pi\varepsilon_0}\left(1 + \frac{1}{2}\frac{v^2}{c^2}\right)\ln\frac{R_2}{R_1}, \tag{6.18}$$

$$\varphi_e = \varphi_{es.e} + \varphi_{ek.e} = \frac{\lambda_e}{2\pi\varepsilon_0}\left(1 + \frac{1}{2}\frac{(-v + i/\lambda_e)^2}{c^2}\right)\ln\frac{R_2}{R_1}. \tag{6.19}$$

The wire connecting the voltmeter to the inner surface is also within the electric field at distance R_1 from the carriers, but it is moving relative to the cylinder, that is why the above formulas cannot be used for calculating the potential. The potentials of the electric fields created by the charge carriers at the conductor's location will be expressed by formulas (6.21) and (6.22),

$$\varphi_{cond.i} = \frac{\lambda_i}{2\pi\varepsilon_0}\ln\frac{R_2}{R_1}, \tag{6.20}$$

$$\varphi_{cond.e} = \frac{\lambda_e}{2\pi\varepsilon_0}\left(1 + \frac{1}{2}\frac{(i/\lambda_e)^2}{c^2}\right)\ln\frac{R_2}{R_1}. \tag{6.21}$$

The sum of potentials (6.18), (6.19) and potentials (6.20), (6.21) is the resulting potential of the cylinder's inner surface, and since the cylinder's outer surface has a zero potential, the required voltmeter readings will equal this resulting potential,

$$U = \varphi_i + \varphi_e + \varphi_{cond.i} + \varphi_{cond.e} = \left(-\frac{iv}{2\pi\varepsilon_0 c^2} + \frac{i(i/\lambda_e)}{2\pi\varepsilon_0 c^2}\right)\ln\frac{R_2}{R_1}\ . \tag{6.22}$$

The first summand of the right-hand side of relation (6.22) characterizes the influence of the cylinder's speed upon voltage U, the second summand accounts for the dependence of voltage on quantity i/λ_e, which is the speed of conduction electrons relative to the conductor. Comparing solution (6.17) obtained in the work (12, p. 99) with expression (6.22), we will note complete agreement in the results as regards assessment of the influence of the cylinder's speed v on voltage U. As for the influence of electron speed i/λ_e on voltage U, the methods of relativistic electrodynamics proved helpless in solving this problem.

Solving the problem by using the above demonstrated technique is much easier and more illustrative than the "easiest" techniques that relativistic electrodynamics can offer.

The cause of this lies in the fact that this electromagnetic theory cannot do without a magnetic field as an independent entity, which emerged from an experiment (the Biot-Savart law) and which, instead of test charge, requires a special instrument for its detection: a current-carrying coil of wire. As soon as the idea of using a magnetic field is abandoned, the problem becomes much easier, which was demonstrated above for instances of rectilinear translational motion of charge carriers. In STEP, the postulates of electromagnetic theory make room for conclusions obtained by means of careful consideration and demonstrative proof. As for curvilinear and rotational motions, things are somewhat more complicated, but not hopeless.

Conclusion

The chief result of the study is development of the fundamentals of the systematic theory of electrical phenomena, which is an alternative to the existing set of empirical laws along with their formal mathematical generalizations that constitute the basis of the contemporary theory of electromagnetism.

The developed fundamentals of the systematic theory of electrical phenomena:

- provide adequate description of electrical phenomena since they are able to predict the results that are in complete agreement with experimental evidence presented in the form of the laws of the classical electromagnetic theory;
- logically follow the basic points of theoretical mechanics without denying them as it is characteristic of electromagnetic theory;
- give a new systematic comprehension of the objective nature of electrical phenomena, which was hidden behind its empirical manifestations in the form of the laws of a traditional electromagnetic theory;
- enable application of much simpler mathematical techniques than those used in contemporary electrodynamics for solving theoretical and applied problems;
- facilitate studying the theory of electricity owing to the systematic arrangement of its conceptual framework;
- possess a wider deductive resources as compared to electromagnetism, that enable us, for instance,

– to imagine the whole set of empirical laws and postulates that form the basis of the classical theory of electricity, as the manifestation, in one form or another, of the energy possessed by the electrical field of charge carriers;

– to provide theoretical grounding for phenomena that either get inadequate description in terms of classical theory, as for instance, the interaction of charge carriers with violation of the principle of equality of action and reaction, or fail to find their theoretical explanation, as is the case with the problem of atomic stability;

– to clarify some results of electromagnetic theory, i.e. the Lorentz force formula, the structure of Ampere's forces etc.;

– to demonstrate the role of conductors' ionic lattice in force interaction of current-carrying conductors.

Development of the theory is directed towards investigation of the electric field properties not only for rectilinear translational motion, but for other types of charge carriers' motion such as rotation, movement along the trajectories of arbitrarily changing curvature. Research along these lines should introduce clarity in determining physical causes that provide for atomic stability.

A rather important methodological procedure that was used in the development of the theory and that has a significant cognitive and scientific value in itself is the systematic parameterization of the electric field, which serves as the basis for the carrier set of the theory, that is, the system of quantities providing objective representation of the electromagnetic field properties.

Parameterization rests on the principle in accordance with which the system of physical quantities, meant for full and adequate representation of the electric field properties, should include only those that may be expressed by partial derivatives of function of potential and (or) kinetic field energy with respect to certain arguments. Such parameterization has at least two distinctive advantages:

firstly, it initially helps eliminate inner contradictions from the carrier set of the theory as well as from the theory itself;

secondly, it renders the signature of the theory transparent, since all the quantities are the derivatives (of some order) from one and the same function, which obviates the need for a specially arranged search of correlations between the quantities constituting the system.

Systematic parameterization described herein with regard to the electric field, may be applied, virtually without alterations, in studies of a gravitational field. It will give a new insight into the properties of this field, and determine possible avenues for experimental studies.

References:

1. *Barett T, Grimes D. Advanced Electromagnetics. Singapore, World Scientific, 1995.*
2. *Bearden T. Energy from the Vacuum. Cheniere Press, Santa Barbara, California, 2002.*
3. *Feynman R, Leighton R, Sands M. Fejnmanovskie lekcii po fizike [The Feynman lectures on physics. Issue 5, Electricity and magnetism]. 3rd edition. Moscow, Izdatel'stvo URSS Publ., 2004; 304.*
4. *Irodov IE. Jelektromagnetizm. Osnovnye zakony [Electromagnetism. Basic laws]. Moscow, Laboratorija Bazovyh Znanij, 2000; 352.*
5. *Javorskij BM, Pinskij AA. Osnovy fiziki [Foundations of physics. Vol. 2]. 2nd edition. Moscow, Nauka Publ., 1974; 464.*
6. *Kolonutov MG. Electrodynamics as the Mechanics of Electric Field: Eastern European Scientific Journal (Gesellschaft swissen schaften). Düsseldorf, Auris Verlag, 2015; 27-40.*
7. *Lakhtakia A. Essays on the Formal Aspects of Electromagnetic Theory. Singapore, World Scientific, 1993.*
8. *Lehnert B. A Revised Electromagnetic Theory with Fundamental Applications. Stockholm, Swedish physics archive, 2008; 158.*
9. *Lehnert B, Roy S. Extended Electromagnetic Theory. Singapore, World Scientific, 1998.*
10. *Matveev AN. Mehanika i teorija otnositel'nosti [Mechanics and the theory of relativity]. Undergraduate textbook. 3rd edition. Moscow, Mir i obrazovanie Publ., 2003; 432.*
11. *Maxwell J. Rechi i stat'i [Speeches and articles]. Ed. by Mitkevich VF. Moscow, Gosudarstvennoje izdatel'stvo tehniko-teoreticheskoj literatury Publ., 1940; 232.*
12. *Meerovich JeA. Metody reljativistskoj jelektrodinamiki v jelektrotehnike [Methods of relativistic electrodynamics in electrical engineering]. Moscow, Leningrad, Jenergija Publ, 1966; 192.*
13. *Moon P, Spencer A. Some electromagnetic paradoxes. Journ.of the Francl. Inst., Nov. 1955, vol. 260, no. 5.*
14. *Multanovskij VV, Vasilevskij AS. Kurs teoreticheskoj fiziki. Klassicheskaja jelektrodinamika [A course in theoretical physics. Classical electrodynamics]. 2nd edition. Moscow, Drofa Publ., 2006; 348.*
15. *Popov VS, Karnakov BM. Atom vodoroda v sil'nom magnitnom pole [Hydrogen atom in a strong magnetic field]. UFN Publ., vol. 184, no. 3.*
16. *Purcell E. Jelektrichestvo i magnetizm [Electricity and Magnetism]. Moscow, Nauka Publ., 1971; 448.*
17. *Shimony K. Teoreticheskaja jelektrotehnika [Theoretical electrical engineering]. Moscow, Mir Publ., 1964; 774.*
18. *Sivuhin DV. Obshhij kurs fiziki [General course of physics, Vol.3: Electricity]. 4th edition. Moscow, Izdatel'stvo MFTI, Fizmatlit Publ., 2004; 656.*
19. *Tamm IE. Osnovy teorii jelektrichestva [Fundamentals of the theory of electricity]. 8th edition. Moscow, Nauka Publ., 1966; 624.*

20. *Vysockij MI, Godunov SI. Kriticheskij zarjad v sverhsil'nom magnitnom pole [Critical charge in a superstrong magnetic field]. UFN Publ., vol. 184, no. 2.*