The theory of electromagnetic field motion. 2. Principle of electromagnetic field component motion

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The paper presents, from the relativistic point of view, the investigations of some logical contradictions, or paradoxes, which arise in stationary processes of electric current-carrying circuit movement as a whole or in movement of separate parts of the circuit. The case of interaction between the two fields having independent sources that move at various velocities is also considered. To characterize unambiguously the state of electromagnetic field, it was necessary to specify additionally the velocities of its components. The interrelationship between Poynting vector and the field velocity is shown.

2.1. Introduction

As we have noted in the paper [1], both internal logical contradictions, and contradictions with the special relativity theory are peculiar to the classical electromagnetic theory. These paradoxes arise contrary to the standard opinion that the classical electromagnetic theory and the relativity theory in the part concerning the electromagnetic field are integrated and complement each other.

The purpose of the present work is to consider specified contradictions of the theory, to analyze the reasons of their occurrence and the way to eliminate them with reference to stationary electromagnetic processes.

2.2. Unipolar generator

The classical theory considers Maxwell's equations to have general and universal character, and the theory of the electromagnetic field is often built on the basis of Maxwell's equations. Nevertheless, unipolar induction is widely known where Maxwell's equations appear to be inapplicable to calculate the electromotive force in an electric circuit.

The unipolar generator (fig. 2.1) represents a metal disk rotating in a homogeneous magnetic field B round OK_2 axis. The voltmeter V by means of sliding contacts is connected to the generating line of the rotating disk at point K_1 and to the axis OK_2 at point K_2. The voltmeter, the axis OK_2 and the rotating disk form the closed circuit S. In the circuit S the electromotive force (EMF) $\mathscr{E}$ *appears* which may be calculated without difficulties on the basis of the Lorentz force. At the same time it follows from Maxwell's equations that EMF $\mathscr{E}$ must be equal to zero because the magnetic flux through the circuit *S* remains constant in time, and in particular, in fig. 2.1, the flux is equal to zero. The above-mentioned relates in full to magnetohydrodynamic generators where instead of a rotating disk there is used fused metal or ionized gas which moves linearly between magnet poles.

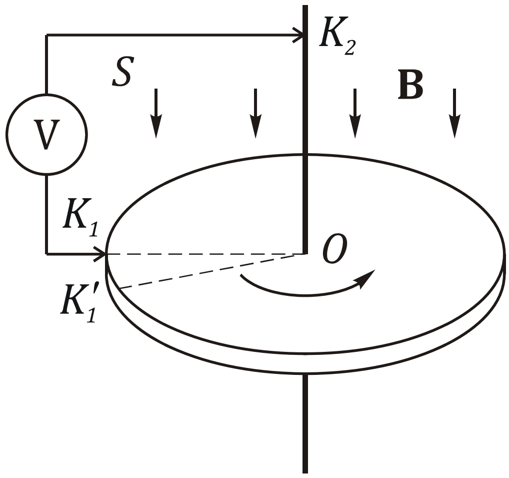

Fig. 2.1. The unipolar generator

Another unipolar generator design different from that shown in fig. 2.1 is often presented in the literature where an external magnetic field is absent but a cylindrical permanent magnet rotates about its axis. Such a generator design is considered, in particular, in the monograph by I.E. Tamm [2]. The generator with a magnet rotating about its axis will be considered in more detail in Chapter 5, since processes in such a generator are fairly more difficult though the final result is the same.

Calculations of EMF $\mathscr{E}$ in [2] are based on the fact that the initial circuit *S*, OK_1K_2O circuit, will be transformed into $OK'_1K_1K_2O$ circuit within time dt , what results in EMF $\mathscr{E}$ that appears in the circuit *S*. Such an approach is widely used to calculate EMF $\mathscr{E}$ of a unipolar generator and also leads to correct numerical results but it does not deny the fact that the magnetic flux through the real circuit OK_1K_2O remains constant in time and hence the EMF E must be equal to zero. Tamm puts forward the following objections against using in calculations the Lorentz force which is closely connected with the concept of magnetic field lines; "Last century there was a prolonged vigorous debate concerning unipolar induction connected with the attempts to interpret this phenomenon in the sense that magnetic field lines excited by a permanent magnet rotate together with a magnet about its axis. It is the movement of the magnetic field lines that cross the conductor *AVB* (K_1VK_2 in fig. 2.1 – *author`s comment*) which was considered a source of inductive electromotive forces occurred in this conductor. It goes without saying that such an interpretation is no good at all: field lines are only an auxiliary concept that serves to describe the field but not any material formations, whose separate elements it would be possible to individualize, to connect them with certain field sources (impossibility of that is especially clear, for example, in the case when fields of two magnets are superimposed – of a mobile magnet and an immovable one) and to watch their motion in space and etc.".

We have cited such an extensive quotation because it contains the basic objections formulated in a concentrated manner made by supporters of an axiomatic model of the electromagnetic field based on Maxwell's equations, and opponents of Faraday's model based on the concept of field lines. As a matter of fact, lines of force are only an auxiliary, conditional concept. However, this conditional concept is fairly accurate and, what is principal, quite clearly reflects some basic properties of the electric and magnetic field. It is not by chance that in the description of fluid and gas streams the concept of current streamlets is widely used despite the evidence of a physical model in the form of a molecular flow. The electric or magnetic field is impossible to represent in the form of a particle flux, but from the mathematical point of view it is a vector flux, therefore the physical model of the electromagnetic field on the basis of Faraday's field lines adequately reflects the basic properties of the space and electromagnetic field and is quite natural.

2.3. Charge movement over a current-carrying wire

Nevertheless, Faraday's model in that form as it exists now does not always unambiguously describe electromagnetic processes. Let us show it using as an example the problem presented in "The Feynman lectures on physics" [3]. This example is also given in many other monographs and educational aids.

A negative charge q moves along a wire carrying a current I with a velocity v_0 in a reference frame S (fig. 2.2*a*). The Lorentz force **F** directed towards the wire acts on the charge and is equal to, $\mathbf{F} = q\,[\mathbf{v}_0\mathbf{B}]$, where **B** is the magnetic field induction at the point of charge, and $\mathbf{v}_0$ is the velocity of this charge.

In the reference frame S' (fig. 2.2*b*) the charge rests, and the wire moves from right to left, as shown in the drawing. On the charge there still acts the force in direction of the wire. As long as the magnetic field does not act on the charge in the reference frame *S´* (it rests), only the electric field that appeared in the reference frame *S′* acts upon the charge. Presence of this field is explained by Feynman, who extremely simplifies a chain of reasoning, as follows.

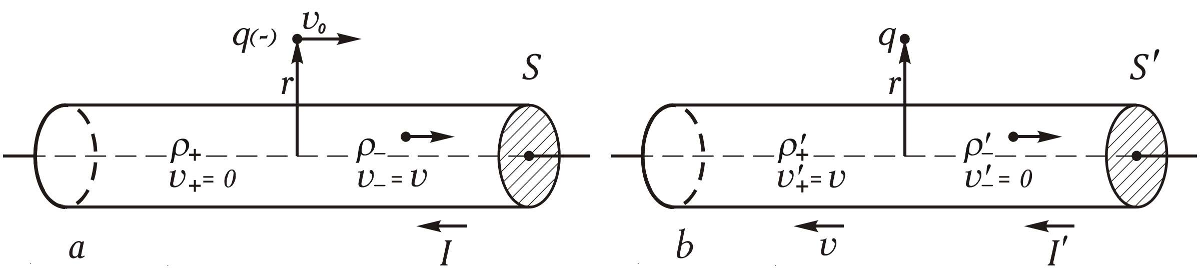

Fig. 2.2. Interaction of a wire carrying the current *I* and particles with the charge *q*, moving at the velocity v_0, in two reference frames.
a – in the reference frame S the wire rests;
b – in the reference frame S' the charge rests.

In the reference frame *S* positive charges of a metal conductor are immovable; the velocity of negative charges (electrons) is accepted to be equal to *v*. In the reference frame *S′* the velocity of positive charges is equal to *v*, whereas negative charges are immovable. Due to relativistic reduction in length an equal number of charges will be in the reference frame *S′* on a segment of the wire length *L* for negative charges and on a segment of the length $L\sqrt{1\text{-}v^2/c^2}$ for positive charges (here, *c* is the constant of the velocity of light). The electric field appears because the positive charge density proves to be larger than the negative charge density.

In monograph [4] a current -carrying solenoid rotating about its axis is considered. On the basis of reasoning based on the length reduction mentioned above and increase in density of moving charges due to this length reduction, the authors draw a conclusion that the rotating solenoid obtains an electric charge distinct from zero. Epithets “apparent charge” and “relativistic effect” do not change anything in essence: such an interpretation contradicts the charge conservation law. Why does this occur?

Let us return to the problem of interaction of a current-carrying conductor with the charge *q* shown in fig. 2.2 but additionally let us take into account the conditions accepted by default. First of all, the wire cannot be of infinite length, but it must be closed in a circuit as shown in fig. 2.3.

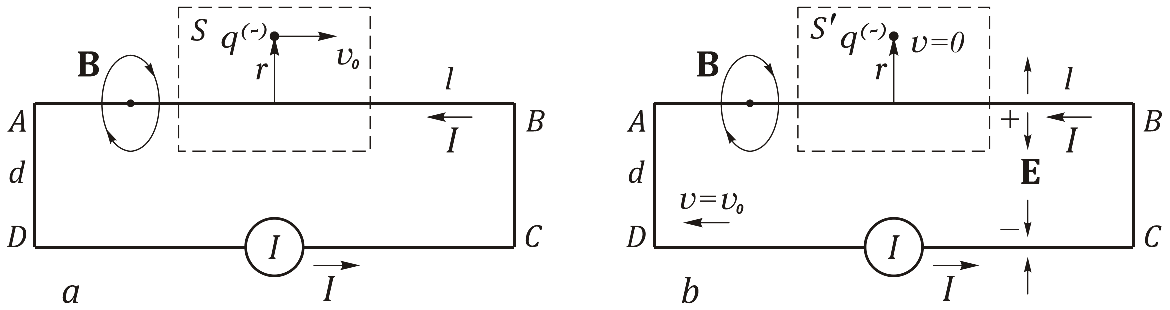

Fig. 2.3. Interaction of a conductor carrying the current *I* with the particle carrying the charge *q*.

In fig. 2.3 a dotted line highlights areas *S* and *S´*, with the area *S* corresponding to the image in fig. 2.2*a* and the area *S´* corresponding to the image in fig. 2.2*b*. Actually, these areas correspond to the stationary laboratory reference frame *S* and the moving reference frame *S´*. A current *I* flows in the circuit *ABCD* that contains a current source designated by *I*. Thus, as well as earlier, in the reference frame *S* in fig. 2.3*a,* a charge *q* moves with a velocity v_0 and in the reference frame *S′* in fig. 2.2*b* the charge *q* rests, and the circuit *ABCD* moves at a velocity v_0 as shown in the drawing. In fig. 2.3 the following designations are used: side *AB* = *l* and side AD = *d*. For the sides *l* and *d* the relation $l >> d >> r$ holds. The same relation was also meant by default in fig. 2.2 though it was not represented in explicit form since the circuit itself is not shown in the drawing. The magnetic field **B** circles round every wire of the circuit *ABCD*, and near the segments *AB* and *CD* in fig. 2.3*b* the electric field **E** is present as well (we exclude the circuit segments *AD* and *BC* out of consideration in view of their remoteness from the areas *S* and *S´* selected by the dotted line but we shall remember that these segments close the circuit and their presence is essentially important).

Let us change the design of the circuit *ABCD* at the expense of extension of the wire *AB* length, as shown in fig. 2.4, and in points *A* and *B* we make movable contacts so as the wire *AB* and the current source *I* together with a part of the circuit *ADCB* could move to the left and to the right independently from each other. As well as earlier, in the reference frame *S* in fig. 2.4*a* the charge moves, and in the reference frame *S′* in fig. 2.4*b* the charge is immovable. Let us consider some special cases of wire and current source movement.

1. In fig. 2.4*a* the wire and the current source with the parts of a circuit attached to it are immovable. In the reference frame S the Lorentz force **F** acts upon the charge. This case completely corresponds to the case presented in drawings 2.2*a* and 2.3*a*.

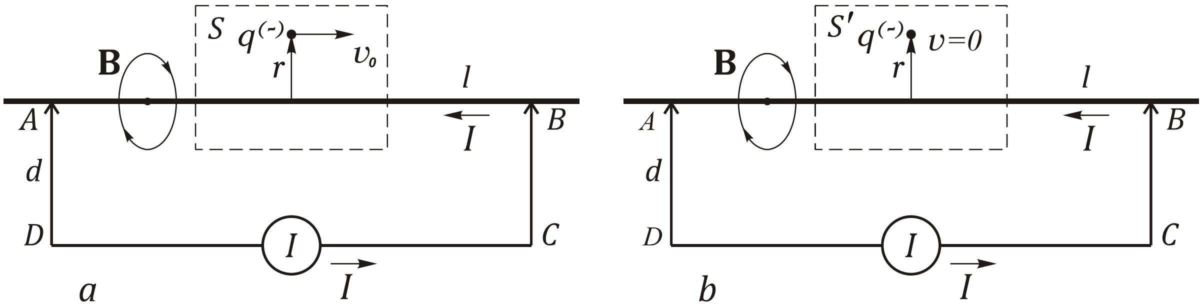

Fig. 2.4. Circuit carrying the current *I* equipped with sliding contacts.

2. In fig. 2.4*b* the wire is immovable, the current source and the elements of a circuit connected to it move at the same velocity and in the same direction as the charge *q*.

If for this case there are only considered the areas *S* and *S´* that are marked out by a dotted line, they will seem absolutely identical to the reference frames *S* and *S´* in fig. 2.2. Despite it, the electric field in fig. 2.2*b* is present in the reference frame *S´*, whereas in the area *S´* marked out by a dotted line in fig. 2.4*b*, the electric field is absent. We would try to understand the reasons of such a situation. With that end in view we consider in more detail, by what the area *S´* marked out in the drawing of fig. 2.3*b* differs from that in the drawing of fig. 2.4*b* (we remind that drawing 2.3*b* is a more detailed image of conditions of the mental experiment in drawing 2.2*b*).

First of all, let us notice that there is nothing to depend on movement of the current-carrying wire in fig. 2.4*b*, at whatever velocity the wire moves, the electric field in the area *S´* will not appear. The reason is that the irrespective of wire movement the *current-carrying circuit ABCD remains immovable* while in fig. 3*b* this circuit moves. Let us return to the area *S´*. It is obvious that the reason of the electric field **E** to occur in this area is the difference of the magnetic field **B** from 0. The field **B** in this area is possible to be considered as definitely set if we can predict presence and the value of the electric field strength **E**. However, the magnitude of the field **B** in the drawings of fig. 2.3*b* and 2.4*b* is identical, whereas the magnitude of the field **E** is different. This contradiction is easily explained if one recognizes that the reason of occurrence of the electric field **E** is the movement of the magnetic field **B** at a velocity v_0 together with the field source whose part is played in the present case by the current-carrying circuit *ABCD*. In the reference frame *S'* in fig. 2.4*b* the charge and the source of the magnetic field (a circuit with current) are immovable relative to each other and to the reference frame *S´* and, hence, the electric field **E** is absent. In fig. 2.3*b* the source of the magnetic field (a current-carrying circuit) moves relative to the reference frame *S´* and, hence, according to Lorentz transformations for the electromagnetic field, the electric field **E** appears.

Thus, let us repeat that the reason of occurrence of the electric field and, accordingly, a linear charge on a wire (segment *AB* of the current-carrying circuit) is the velocity of the magnetic field which is not zero. We notice that on the segment *CD* of a circuit under current there will be a negative linear charge. In drawing 2.3*b* positive and negative linear charges are designated accordingly by signs "+" and "–". On the whole, the charges will counterbalance each other, and the circuit at the current *ABCD* in the reference frame *S´* as well as in the frame *S* remains neutral. As one would expect, the law of charge conservation is not violated when transition is made from the immovable reference frame *S* to the moving inertial reference frame *S´* if the entire circuit is considered but not a separate part of the circuit.

Another explanation of the reason for occurrence of the electric field as mentioned above consists in relativistic reduction of length of any part of the wire, which is disproportionate for positive and negative charges. The same reasoning presented in [3] are also valid for the case in fig. 2.4 when a charge *q* and a current source *I* with adjoining parts of the circuit move with an identical velocity (fig. 2.4*a*). In fig. 2.4*b* the marked area *S´* is absolutely the same as that in fig. 2.3*b*, hence, on the segment of the wire *AB* there should be an excess of positive charges, and the segment *CD* of the circuit in fig. 2.4*b* is a usual immovable part with the current which, as it is known, always remains neutral. If we consider the circuit *ABCD* as a whole we shall find out an excess of positive charges that results in infringement of the charge conservation law since the circuit *ABCD* in fig. 2.4*a* is initially accepted as neutral.

The inconsistency of the presented above explanation of the reason of the electric field and the linear charge to occur in a moving wire is in the fact that for negative and positive charges there were compared the lengths of wire segments that have been measured in different reference frames – immovable and mobile. For correct comparison the lengths of the chosen segment must be compared in the same system, immovable or mobile. In that case it will appear that in any segment of the wire there is always identical quantity of negative and positive charges.

The conclusion drawn in monograph [4] that during rotation of a solenoid about its axis the electric charge occurs on its surface is erroneous for the same reason. When the solenoid rotates considering solenoid coils closed (it does not break the generality of conclusions since a solenoid, for example, can be made of superconducting material), only coil material rotates and a current-carrying circuit of each coil remains invariable in the configuration and immovable. Hence, the magnetic field is also immovable, for this reason neither electric field nor charges appear on the surface of the solenoid. Accordingly, the charge conservation law is not violated.

2.4. Case of two independent field sources

The conclusion that the magnetic or electric field must be characterized not only by magnitude but also by velocity is not new. In the special theory of relativity the question, perhaps, does not arise: if the charge can move relative to the magnetic field, the magnetic field also can move relative to the charge, otherwise we shall come to infringement of the relativity principle. In the references devoted to the classical theory of the electromagnetic field it is not always possible to find out the author`s position, sometimes this position is expressed obviously as in the citation resulted above from monograph [2], but it is more often expressed implicitly in favor of one or another position.

Now, let us try to answer another question put in the citation whether it is possible to connect field lines to certain field sources. With that end in view let us consider a system consisting of two circuits, shown in fig. 2.5.

The circuit *ABCD* with a current I_1 is immovable, and the circuit *MNOP* with a current I_2 and a charge q move at a velocity **V**. The segment *MN* of the circuit is a hollow metal cylinder located coaxially relative to the segment *AB* of the circuit. Likewise we have done earlier, the reference frame which is immovable relative to the circuit *ABCD* will be designated as *S*, and the reference frame, which is immovable relative to the circuit *MNOP* and the charge *q*, will be designated as *S´*. We shall consider that the aspect ratio accepted for the circuit *ABCD* in fig. 2.3 is the same for the both circuits in fig. 2.5. The diameter of the hollow cylinder *MN* is much less than its length. If these requirements are met, it is possible to consider with sufficient accuracy that the magnetic field **B** in the point *r*, where the charge *q* is positioned, is equal to zero when currents I_1 and I_2 are equal to each other.

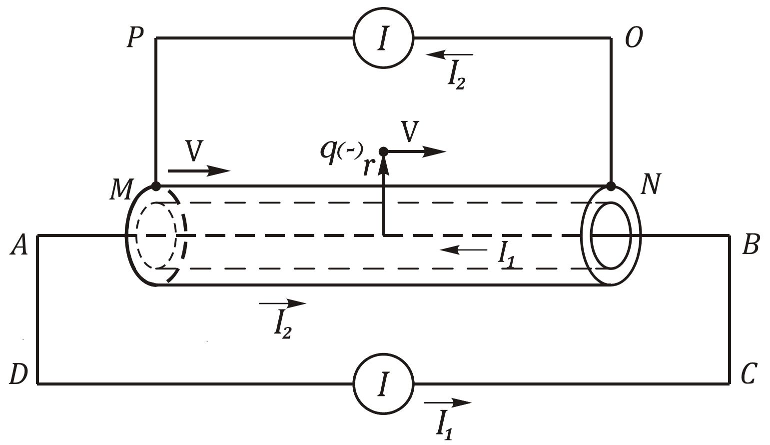

Fig. 2.5. System consisting of two current-carrying circuits. Circuit *ABCD* is immovable, whereas circuit *MNOP* and charge *q* move at velocity **V**.

Let us consider three cases:

a) The current in the circuit *ABCD* is switched on, the current in the circuit *MNOP* is switched off (I_2 = 0);

b) The current in the circuit *ABCD* is switched off (I_1 = 0), the current in the circuit *MNOP* is switched on;

c) The current in both circuits is switched on, $I_1 = I_2$.

Case a) was considered above; it is completely equivalent to the case shown in fig. 2.3.

In case b) the circuit *MNOP* in the reference frame *S´* induces the magnetic field in the point *r* but it does not interacts with a charge *q* because the circuit and the charge are immovable relative to each other. The circuit *MNOP* in the reference frame *S* also induces the electric field in the point *r* in addition to the magnetic field. Action of this field on the charge *q* is completely compensated by the Lorentz force since the charge moves in the magnetic field. Thus, the net force is equal to zero, as well as in the reference frame **B.**

In case b) two approaches to estimate the force acting on the charge are possible. In the first approach, at first we calculate the magnetic field induction **B** in the point *r* but it is equal to zero under condition of equality of currents I_1 and I_2, then we draw a conclusion that so far as **B** is equal to zero, the Lorentz force in the reference frame *S'* and the electric field in the reference frame *S* are also equal to zero, hence, and the force applied to the charge is equal to zero, too. This conclusion comes into conflict with the conclusion drawn earlier that the current I_2 in the circuit *MNOP* does not interact with the charge because the charge and the circuit are both immovable. In fact, if the current in the circuit *MNOP* is switched off we shall come to case a) where the force acts on the charge and this force becomes zero when the current is switched on.

This contradiction disappears in the second approach. As an initial condition, let us accept case a) when the current in the circuit *MNOP* is switched off. In this case there is an electromagnetic field in the reference frame *S'* with a magnetic component **B** and an electric component **E**. When the current in the circuit *MNOP* is switched on, the magnetic component **B** is compensated by the magnetic field induced by the current I_2 and becomes equal to zero, but the electric component of the electromagnetic field remains unchanged and, hence, the force acts on the charge, which is unchanged when the current in the circuit *MNOP* is switched on or off. This force is also maintained in the reference frame *S*, and in the case of high velocities it is to be recalculated using the laws of relativistic mechanics. Direct calculation of this force in the reference frame *S* leads to logical difficulties, which are, however, quite surmountable.

Let us consider more in detail the forces that act in the reference frame *S*. When in the circuit *MNOP* the current is switched off, the Lorentz force acts on a charge from the current I_2 of the circuit *ABCD*. When the current is switched on in the circuit *MNOP* in the reference frame *S* the electric field **E** appears, the Lorentz force disappears, as magnetic fields caused by currents I_1 and I_2, mutually compensate each other. At the same time, despite presence of the electric field **E,** it does not act upon the charge. The electric field **E** is induced by the current I_2 in the circuit *MNOP*, hence, if the electric field **E** acts on the charge, the charge and the circuit interact, and a force is applied to the circuit due to the charge, which is in contradiction to that mentioned earlier. Not only current switching off, but also any change in I_2 current value does not lead to the change of the force acting upon the charge.

Earlier, we have obtained a correct result by considering case b), the equality of the force to zero in the reference frame *S*, by introducing fictitious forces compensating each other: the Lorentz magnetic force and electric force. These forces are fictitious, as they are absent in the reference frame *S'*, and the force which is nonzero in any single inertial reference frame, must also be nonzero in any other inertial reference frame, as follows from the equations of relativistic mechanics.

The approach based on separate calculation of fields and forces independently for each source with subsequent summation allows to a considerable extent overcome logical difficulties arising in the presence of two or more field sources. This approach is developed in the further work of the present cycle.

2.5. Velocity of electromagnetic field components

Thus, distribution of the "velocity" concept to electric and magnetic components of the electromagnetic field allows to eliminate some logical contradictions of the classical theory and completely agrees with the special theory of relativity. The velocity of the electromagnetic field component corresponds to the velocity of a source. The field source is meant to be a physical object causing occurrence of the field invariable in time and space in its own reference frame where the object is immovable. In the present chapter it is supposed that such an object exists but other cases will also be considered hereinafter. A set of two or more elementary physical objects which are invariable in time and space can serve as a field source, which assumes their mutual immovability or mutual indemnification of movement effects, as for example, it is valid for free electrons on the plates of the plane capacitor. The capacitor as a whole must be considered as a single source of the electric field. Later, we shall consider such a set of elementary sources as a single field source.

In the case of one (single) field source, only one field component exists in its own reference frame of the moving field source. Let us designate this field as a self-field, the electric field $\mathbf{E}_0$ or the magnetic field $\mathbf{B}_0$ depending on what field we consider, and the reference frame – as an intrinsic reference frame of the said electromagnetic field. We underline that, by definition, in the intrinsic reference frame only one of the field components exists, electric or magnetic. This circumstance allows to simplify Lorentz transformations for the self–field. Now, we give these transformations in a vector form.

Let us consider the case of the self- field $\mathbf{E}_0$. Lorentz transformations for longitudinal $\mathbf{E}_{\parallel}$ and transversal $\mathbf{E}_{\perp}$(relative to the intrinsic velocity of the electric field $\mathbf{V}_e$) components of the electric field $\mathbf{E}$ in the immovable reference frame become (hereinafter all equations are used in SI system of units):

$$\mathbf{E}_{\parallel} = \mathbf{E}_{0\parallel}, \qquad \mathbf{E}_{\perp} = \frac{\mathbf{E}_{0\perp}}{\sqrt{1-\frac{V_e^2}{c^2}}} \tag{2.1}$$

where $\mathbf{E}_{0\parallel}$ and $\mathbf{E}_{0\perp}$ F are longitudinal and transversal components of the intrinsic electric field, and c is the velocity of light in vacuum.

The equation for the transversal component contains only one term because there is no magnetic field in the intrinsic reference frame in the case under consideration.

The equation for the magnetic field $\mathbf{B}$ in the immovable reference frame becomes:

$$\mathrm{B} = \frac{1}{c^2\sqrt{1-\frac{V_e^2}{c^2}}}[\mathrm{V}_e\mathrm{E}_0]. \tag{2.2}$$

We would remind that the magnetic field in the intrinsic reference frame is absent, for this reason the equation contains only one term on the right, the field $\mathbf{B}$ does not contain a longitudinal component and is always orthogonal to the velocity $\mathbf{V}_e$.

By inserting value $\mathbf{E}_{0\perp}$ from (2.1) into (2.2) and considering that replacement $\mathbf{E}_{\perp}$ by $\mathbf{E}$ does not change either direction or magnitude of the resultant vector in the cross-product, we finally obtain:

$$\mathrm{B} = \frac{1}{c^2}[\mathrm{V}_e\mathrm{E}]. \tag{2.3}$$

Expression (2.3) is actually the same Lorentz transformation (2.2) but unlike (2.2), it includes only the values from the laboratory reference frame. The velocity $\mathbf{V}_e$ is a velocity of the electric field $\mathbf{E}$ in the immovable reference frame. The magnetic field **B** is absent in the moving reference frame, in the immovable reference frame it is immovable.

For the case with the intrinsic magnetic field $\mathbf{B}_0$ we have absolutely similarly:

$$\mathbf{B}_{\parallel} = \mathbf{B}_{0\parallel}, \qquad \mathbf{B}_{\perp} = \frac{\mathbf{B}_{0\perp}}{\sqrt{1 - \frac{V_e^2}{c^2}}} \tag{2.4}$$

and

$$\mathbf{E} = -[\mathbf{V}_m \mathbf{B}]. \tag{2.5}$$

From expressions (2.3) and (2.5) it is possible to calculate an intrinsic velocity $\mathbf{V}_e$ or $\mathbf{V}_m$ depending on whether the field, electric or magnetic, is intrinsic. In turn, it is possible to estimate a field type depending on the sign of an invariant I_1:

$$I_1 = c^2 B^2 - E^2. \tag{2.6}$$

If the invariant is $I_1 > 0$, the electromagnetic field can be reduced to a purely magnetic field by choosing a relevant reference frame. In the accepted terminology it means that the intrinsic field in this case is a magnetic field, and to estimate the intrinsic velocity $\mathbf{V}_m$ it is necessary to use expression (2.5).

If the invariant is $I_1 < 0$, the electromagnetic field is reduced to the electric field, and to estimate the intrinsic velocity $\mathbf{V}_e$ it is necessary to use expression (2.4).

To determine the type of a self-field by means of the sign of an invariant (2.6) is necessary when it cannot be made proceeding from statements of the problem. If statements of the problem define only the fields **E** and **B** which can be formed by superposition of several fields or cannot have in general a source as “a physical object causing occurrence of the field invariable in time and space in the intrinsic reference frame”, we find, as described above, the self-field and the velocity of the virtual source that causes the fields **E** and **B** to occur in the stationary laboratory reference frame.

From expression (2.3) we find the velocity $\mathbf{V}_e$. For this purpose let us multiply the both parts of expression (2.3) by the vector of the transversal component of the electric field strength $\mathbf{E}_\perp$:

$$[\mathbf{E}_\perp \mathbf{B}] = \frac{1}{c^2}[\mathbf{E}_\perp[\mathbf{V}_e \mathbf{E}]] = \frac{1}{c^2}(\mathbf{V}_e(\mathbf{E}_\perp \mathbf{E}) - \mathbf{E}(\mathbf{E}_\perp \mathbf{V}_e)). \tag{2.7}$$

Taking into account that $[\mathbf{E}_\perp \mathbf{B}] = [\mathbf{EB}]$, $(\mathbf{E}_\perp \mathbf{E}) = E_\perp^2$, $(\mathbf{E}_\perp \mathbf{V}_e) = 0$, and $(\mathbf{E}_\perp \mathbf{V}_e) = 0$, we finally obtain from (2.7):

$$\mathbf{V}_e = c^2 \frac{[\mathbf{EB}]}{E_\perp^2}. \tag{2.8}$$

Similarly, multiplying both sides of equation (2.5) by the vector of the transversal component of the magnetic induction $\mathbf{B}_\perp$, we obtain:

$$\mathbf{V}_m = \frac{[\mathbf{EB}]}{B_\perp^2}. \tag{2.9}$$

Equations (2.1), (2.3) and (2.4), (2.5) are of fundamental importance in the theory of electromagnetic field movement and on the whole in the relativistic electromagnetic theory. When it is not required to consider the value of the self-field directly and only field characteristics in the laboratory reference frame are important, and this relates to the majority of electromagnetic problems, equations (2.3) and (2.5) will be enough.

We would notice that the numerator in expressions (2.8) and (2.9) is, actually, Poynting vector **S**:

$$\mathbf{S} = \varepsilon_0 c^2 [\mathbf{EB}], \tag{2.10}$$

where ε_0 is an electric constant.

Substituting (2.8) and (2.9) in (2.10), we obtain other useful relations:

$$\mathbf{S} = \varepsilon_0 E_\perp^2 \mathbf{V}_e \tag{2.11}$$

and

$$\mathbf{S} = \varepsilon_0 c^2 B_{\perp}^2 \mathbf{V}_m . \qquad (2.12)$$

From expressions (2.11 (2.12) it follows that Poynting vector **S** and the intrinsic velocity vector **V** are collinear, as one would expect.

We would notice that for any electromagnetic field with components **E** and **B** formally two solutions exist for the intrinsic velocity in the form of (2.8) and (2.9). One of these solutions corresponds to the velocity of a self-field which always less or is equal to the velocity of light. It is this solution that has a physical meaning within the scope of the present article. As follows from expression (2.1) the self-field $\mathbf{E}_{0\perp}$ should have an imaginary value at the velocity $\mathbf{V}_e$, exceeding the velocity of light *c*, since the self-field **E** is a real value. The same relates to the magnetic field **B**. Also, in certain cases it is impossible to ignore the second solution. The physical meaning of the second solution leading to an intrinsic velocity exceeding the velocity of light will be considered in the subsequent papers of the cycle.

Equations (2.3) and (2.5) have the solution at any directions of the velocity vector, however, the inverse problem, the calculation of the intrinsic velocity using equations (2.8) and (2.9) under condition of parallelism of the self-field and the intrinsic velocity leads to an uncertainty of 0/0 type. In this case, the intrinsic velocity should be estimated proceeding from the statements of the problem on the field source velocity. Fortunately, such a situation can usually be found when the field source is known in an explicit form, and when it does not exist as a physical material object, the field and velocity vectors are orthogonal.

It should be noticed that, nevertheless, the concept of "velocity" as a characteristic of the field state in equal extent relates to both collinear and orthogonal components. In more detail this subject will be considered later, while we only notice that there are no grounds for an opposite position.

Conclusions

1. Electric field strength and magnetic field induction do not characterize definitely the state of the electromagnetic field. To characterize definitely the state of the electromagnetic field, it is necessary, in addition, to specify its component velocities.

2. For the case where a field source exists and is the only one, the field velocity coincides with the velocity of the source. Otherwise, it is possible

only to specify the virtual field source causing system electric and magnetic components of an electromagnetic field observed in the laboratory. We shall name the field of such a source in both cases as self-field, and the velocity – as intrinsic field velocity.

3. In the case of several sources, field components from each source must be considered independently.

4. There were obtained equations that link electromagnetic field component values in the immovable laboratory reference frame with the intrinsic velocity of these components.

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To the list of publications

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