American Journal of Modern Physics and Application
2016; 3(1): 1-10
http://www.openscienceonline.com/journal/ajmpa

Relationships between Electromagnetic and Mechanical Characteristics of Electron

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To cite this article

Alexander K. Tomilin, Igor L. Misiucenko, Vladimir S. Vikulin. Relationships between Electromagnetic and Mechanical Characteristics of Electron. *American Journal of Modern Physics and Application.* Vol. x, No. 1, 2016, pp. 1-10.

Received: April 22, 2016; **Accepted**: May 3, 2016; **Published**: June 2, 2016

Abstract

A relationship between electron charge and electron mass was established based on energy relations. A conclusion was drawn about solely electromagnetic nature of mass. Hence, the generalized magnetic field has vortex (vector) components and potential (scalar) component. It was also established that energy of potential magnetic field is negative and constitutes 1/3 of kinetic energy of particle. Besides, the well-known "problem 4/3" is solved successfully.

Keywords

Mass, Charge, Electron Radius, Physical Vacuum, Vector Potential, Energy of Magnetic Field

1. Introduction

The study of interrelations and analogies between mechanics and electrodynamics appears to be a currently relevant and promising scientific problem. Such an approach not only allows to develop and update each of those branches of science, but also to find out new relationships between fundamental constants, to determine the physical essence of notions and postulates that lie at the basis of natural science, to solve the existing problems and explain certain paradoxes.

An idea to present mass of an electron as a purely electromagnetic effect is considered to be very promising [1]. However, up to the present day this idea couldn't be completely worked out, and it was not possible to obtain a self-consistent theory of electromagnetic mass. In our opinion the reason lies in an inadequate model of electron and incomplete knowledge about the electromagnetic field.

Usually a lone electron is considered as a sphere, which is surrounded by vacuum and along the surface of which the charge is spread [1]. Such model calls for the introduction of forces that retain charges on particle surface. Due to this reason "Poincare stresses" are used, which must have a nonelectromagnetic nature. As Feynman noticed, "the beauty of the whole picture disappears at once, everything becomes too complex" [1] in such a model. In other words, Feynman deemed purely electromagnetic explanation to be the most beautiful, but he failed to substantiate it.

Apparently, the explanation of mass as an electromagnetic phenomenon is only possible based on complete and adequate knowledge on the nature of two interrelated phenomena – namely, electric charge and electromagnetic field.

The notion of "vacuum" in the sense of a totally empty space is in contradiction with the close-range interaction principle, on which Faraday, Maxwell, Thomson and Stokes relied upon [2-4]. According to perceptions of the electromagnetism theory founders, all physical interactions take place only under the conditions of compulsory participation of a continuous medium that surrounds the interacting centers [5]. These analogies are used in the published work of P.A. Zhilin to the full extent [6]. With the help of theses analogies he has found out that in the general case magnetic field possesses both vortex and potential components. Similar conclusions were drawn by K. J. van Vlaenderen [7], D. A. Woodside [8], A. I. Arbab, Z. A. Satti [9], D.V. Podgainy, and O.A. Zaimidoroga [10], Alexeyeva L. [11]. Results of their studies formed the basis for the generalized electrodynamic theory [12-15].

The traditional interpretation of electromagnetism is not complete. The usage of Coulomb and Lorentz gages led to the exclusion of potential electromagnetic processes. A number of well-known paradoxes arose as a result: the violation of Newton's third law in the case of electromagnetic interaction [12], the "4/3 problem" [1], [16] and some others.

2. Purpose of the Study

The goals of the present article are:

- to develop a model for an elementary charged particle that would allow to determine the correlation between its charge and mass;
- to eliminate the discrepancy between the kinetic energy of an electron and total energy of its magnetic field (also known as "4/3 problem") on the basis of generalized electrodynamic theory.

3. The Correlation Between Charge and Mass of an Elementary Particle

3.1. The Research Method

The scientific discussion concerning the structure of an electron continues to be of vital importance for many decades [16-22]. A sufficiently complete overview of microcosm structure models is given in the article [22]. Three hypotheses of mass origin are examined – namely, electron theory, Higgs mechanism of the Standard Model and the principle of mass generation in the nonlinear theory of elementary particles. Strengths and shortcomings of each of them are shown as well as the existence of strong connections between them.

Poincare model is further elaborated in several modern researches [18-19]. In particular, it is proposed to view an electron as a multitude of similar particles forming a gravitationally bound system and filling up a certain spherical space [18]. In the process of viewing the internal interactions not only electromagnetic field but also gravitational field are taken into account, as well as acceleration field and pressure field. It is generally thought that all electron properties and all phenomena related to electron can be explained solely by endogenous processes.

In our opinion, Poincare model and its modifications have a critical weakness. It is impossible to use the functions of charge and mass distribution with regard to an elementary particle. This is why internal structural objects that have a charge less than that of an elementary charge cannot be isolated. Such a model cannot be used for the interpretation of nature of an elementary electric charge and electromagnetic field related to it.

Nevertheless, Poincare model has a high-priority advantage – namely, rejection of pointwise idealization and use of certain radius r_e. Let us note that it differs from a well-known traditional electron radius

$$R_e = 2,81 \cdot 10^{-15} m,$$

which determines the size of its effective electric field. It is apparent that in such a model the relation $r_e < R_e$ should be valid.

Another model deems electron to be an electromagnetic process taking place within an area with indistinct boundaries [22]. Under this approach there is no need to introduce forces of non-electromagnetic nature into consideration, and therein its advantage lies. Electric field appears beyond the boundaries of the above-indicated area. This model can be developed and applied for studying the process, which occurs inside the particle, in order to explain the nature of elementary electric charge. The difficulty in the usage of this model lies in the lack of a distinct boundary of the area where the charge is generated [22]. Besides, the issue of surrounding environment and its properties remains open.

In this paper we use the energy method, which is based on a hybrid model of the electron. Let us deem that electron charge is generated by an electromagnetic process localized in the sphere of a certain radius r_e. The value r_e is to be determined. Thus, an electron is deemed to be a localized particle of a spherical shape with a well-defined boundary. The particle has its own charge and mass. Self-electromagnetic field is generated beyond the spherical particle.

The issue of electromagnetic field nature has already been mentioned in the Introduction. This issue is connected with conceptional foundations of natural science. Materialistic concept of close-range interaction denies that vacuum represents absolute emptiness. Empty space that has no physical properties cannot be used in the description of physical interaction even as an abstract term. This is why physicists use term "physical vacuum" - a material continuous medium with known electromagnetic properties. The electron model (suggested by us) assumes that electron is formed by a process going on in this medium (e.g., a toroidal quantum vortex) [22]. Thus, an electron is generated by the material vacuum medium, it is always inside the latter and is inseparable from the latter. Such a model is used, for example, [23].

Within the framework of such theory, the electromagnetic field is presented as a series of disturbances of this medium – namely, currents, deformations and waves. We do not know all medium properties, and even the medium nature itself remains uncertain. That's why the suggested model does not claim to be complete – because it does not describe the electromagnetic process ongoing inside an electron in detail, and, therefore, it does not describe the nature of the charge itself. Our model cannot explain all its quantum properties and stability problem. Nevertheless, it allows to use the notions "charge", "mass", and "field" and to correlate these terms to certain material objects. The interrelation between these objects should be expressed in the form of certain correlations between their physical characteristics.

3.2. Theory

Let us study a charged particle with radius r_e moving linearly and steadily with velocity *v*. For the sake of definiteness, let us deem it as positive and place the observer at a certain point assumed to be unmoving. Entire particle charge q will pass by the observer in a time equal to the ratio of its longitudinal size to its motion velocity:

$$t = \frac{l}{v}.$$

In the general case the linear size of a particle is determined taking into account the relativistic contraction:

$$l = l_0\sqrt{1-v^2/c^2}\,. \quad (1)$$

where $l_0 = 2r_e$.

The observer records the local current:

$$I = \frac{qv}{l}.$$

The energy corresponds to recorded current:

$$W = \frac{LI^2}{2}. \quad (2)$$

Usually inductance L is ascribed to a conductor, but here it should be applied to the charged particle. Such a characteristic is known under the name of "kinetic inductance" [24]. Let us determine the value of kinetic inductance of a spherical particle with radius r_e.

There is no formula for the calculation of spherical conductor inductance in scientific and technical literature, but there is a formula for cylindrical conductor [25]:

$$L = \frac{\mu_0 h}{8\pi} + \frac{\mu_0 h}{2\pi}\left(\ln\frac{2h}{r} - 1\right), \quad (3)$$

where r - cylinder radius, and h – its height.

In the arguments given above we have studied the particle motion on a segment with length $l = 2r_e$. Hence, $h = 2r_e$ in (3). This means that we need to consider and compare the inductances of a sphere with diameter $2r_e$ and cylinder with the same height. In other words, we consider the cylinder and the sphere inscribed into it. However, such a comparison is not quite correct as the cylinder volume and its surface is larger than the corresponding parameters of the inscribed sphere.

This gives rise to an issue of a criterion for which the difference between the inductances of the sphere and cylinder is minimal. We propose to take the equality of sphere and cylinder surfaces as such criterion. In this case the following relationship between the cylinder radius and sphere radius is valid:

$$r = \sqrt{\frac{2}{3}}r_e = 0,8165r_e.$$

The inductance of spherical particle in this case can be calculated with high accuracy according to the following formula:

$$L = \frac{\mu_0 l}{4\pi} = \frac{\mu_0 r_e}{2\pi}. \quad (4)$$

It's worth noting that in the case of modeling a particle with material point, kinetic inductance of this point is lost and it becomes impossible to derive its electromagnetic energy.

After writing down (2) taking (4) into account, we will obtain an expression for current energy:

$$W = \frac{\mu_0 q^2 v^2}{8\pi l}. \quad (5)$$

On the other hand, moving particle with mass m has kinetic energy:

$$K = \frac{mv^2}{2}. \quad (6)$$

Changes in the value of each of these energies represents work of forces that cause accelerating (decelerating) of particle. In essence, formulas (5) and (6) give one and the same value – therefore, they could be equated. Hence we will obtain an expression correlating charge with mass:

$$m = \frac{\mu_0}{4\pi}\cdot\frac{q^2}{l}. \quad (7)$$

Neglecting the relativistic effect, let's assume that $l = l_0 = 2r_e$, and we will derive a value, which is generally agreed to call "rest mass" of charged particle:

$$m_0 = \frac{\mu_0}{8\pi}\cdot\frac{q^2}{r_e}. \quad (8)$$

It is obvious from (7) and (8) that particle mass does not depend on the sign of its charge. In particular, these formulas can be applied to electron. Taking into account the known value of electron rest mass, we will obtain electron radius:

$$r_e = \frac{\mu_0}{8\pi}\cdot\frac{q^2}{m_0} = 1,4\cdot 10^{-15}m, \quad (9)$$

where $m_0 = 9.1\cdot 10^{-31}kg$ - rest mass of electron, $q = 1.6\cdot 10^{-19}C$ – elementary charge, $\mu_0 = 1.256\cdot 10^{-6}\,H/m$ - magnetic permeability of vacuum.

The obtained own radius of electron turned out to be half as large than classical electron radius:

$$R_e = 2.81\cdot 10^{-15}m.$$

Note that Lorentz [21], was almost the same value of a free electron radius:

$$r_e = 1.5 \cdot 10^{-15} m .$$

It's worth noting here that the limiting accuracy of measurements for geometric dimensions is restricted by Planckian length [26]:

$$l_P = 1.6 \cdot 10^{-35} m.$$

Obviously, quantum properties of electron don't exert significant influence on accuracy of electron radius determination (9).

Taking into consideration the used method for mass determination (7), the mass should be called inertial. However, this leads to an issue of gravitational mass and phenomenon of gravitation proper. This issue (plus the problem of equivalence of inertial mass and gravitational mass) will be discussed in one of the subsequent sections.

Let's discuss the obtained result and its validity. We have analyzed the process of acceleration of a single electron and equated the work of accelerating force to kinetic energy acquired by electron. Of course, the energy of electron interaction with physical vacuum changes when an electron is accelerated, and magnetic field is generated. This gives rise to the following question regarding electromagnetic field energy – should we add the energy of electron field to the kinetic energy of electron or not? Such a question involves hypothetic separation of the motion process: at first an electron moving in emptiness is considered (and its kinetic energy is determined), and then an ambient environment is included in consideration and energy of ambient environment disturbance resulting from electron motion is determined. Such an approach is used, for instance, when analyzing the motion of bodies in a viscous medium. However, the thing is that the known expression for kinetic energy was derived for motion of material objects in physical vacuum – not in emptiness. That's why it takes into account the change in energy of object relation with this medium. In our case kinetic energy of electron and energy of electron field are one and the same. Formulas for mechanics and electrodynamics for energy look differently, but they reflect one and the same essence. That's why these energies in our case are equated, rather than being summed up.

As is well-known, particle mass depends on velocity of particle motion:

$$m = \frac{m_0}{\sqrt{1 - v^2/c^2}} . \qquad (10)$$

The value of charge does not depend on particle motion velocity (in contrast to mass). The charge is a relativistic invariant [25]. Obtained relationship (10) is in conformity with these properties of charge and mass. Relativistic increase in mass stems from reduction in particle dimensions in the direction of its motion according to (1).

Let's analyze another elementary particle – namely, proton. It is well-known that proton mass is 1836 times greater than electron mass:

$$m_p = 1.672 \cdot 10^{-27} kg .$$

At the same time proton radius is approximately 3.2 times less than the classical electron radius. Usually the following value is used:

$$R_p = 0.8751 \cdot 10^{-15} m .$$

Reverse nonlinear dependence between mass and size of elementary particles is observed. Hence, true radius of proton calculated using formula (9) is significantly smaller than electron radius:

$$r_p = \frac{\mu_0}{8\pi} \cdot \frac{q^2}{m_p} = 0.761 \cdot 10^{-18} m .$$

Let's calculate the relationship:

$$\frac{R_p}{r_p} = 1150 .$$

The similar relationship for electron is equal to 2.

These relationships verify the above-described standpoint regarding nature of mass – namely, the smaller is the size of elementary particle, the stronger it is connected with physical vacuum.

Of course, this gives rise to an issue of mass of electrically neutral particles – e.g. neutron [16]. It is well known that in free state neutron breaks down to form electron, proton and antineutrino. Hence, it is possible to represent neutron as a set of oppositely charged particles and to determine their total mass taking their interactions with one another into account. The problem of photon mass can be also solved on the basis of comprehensive picture about electromagnetic wave [12].

3.3. Results

1. The suggested model of lone electron enables to adequately describe its motion in the physical vacuum medium and determine electromechanical analogies.
2. The mass of a charged particle is unambiguously determined by its charge and own size, which is calculated in the chosen frame of reference.
3. The mass of moving charged particle in the chosen frame of reference grows depending on velocity solely due to relativistic contraction of its size in the motion direction.

4. Inertia and Gravitation

4.1. Theory

Let us analyze a case of accelerated motion of a charged particle. The convection current won't be direct anymore; therefore its time derivative will be different from zero:

$$\dot{I} = \frac{\partial I}{\partial t} = \frac{\partial}{\partial t}\left(\frac{qv}{2r_e}\right) = \frac{q}{2r_e}a\,, \qquad (11)$$

where $a = \dfrac{\partial v}{\partial t}$ – is particle acceleration.

According to the law of electromagnetic induction, such current causes EMF of self-induction that hinders the change of the current that generates it:

$$U = -L\dot{I}\,.$$

Taking into account (4), it's possible to put down the following:

$$U = -\frac{\mu_0 r_e}{2\pi}\cdot\frac{q}{2r_e}a = -\frac{\mu_0 q}{4\pi}a\,. \qquad (12)$$

The following work is done as a result of charge motion:

$$Uq = -\frac{\mu_0 q^2}{4\pi}a\,. \qquad (13)$$

In the case of positive acceleration work has a negative sign, while in the case of particle deceleration positive work is performed. Let us determine the force that performs this work for motion distance being $2r_e$:

$$F = \frac{Uq}{2r_e} = -\frac{\mu_0 q^2}{4\pi}\cdot\frac{1}{2r_e}a = -ma\,. \qquad (14)$$

Force (14) is directed opposite to the acceleration direction regardless of the charge sign. Hence, that is the inertia force. Thus, the inertia force origin is explained by electrodynamics process.

It is well known that forces emerge as a result of the interaction between material objects. The inertia forces must not be an exception. A charged particle is one of the interacting participants. A question arises about a second participant of this interaction. The model (used by us) assumes that the particle does not move in absolute vacuum, but that it moves in a material medium with physical properties. Such concept has been used in physics in different variations for a long time [28]. The conclusion is that the inertia forces emerge as a result of interaction between bodies and vacuum medium. Within the frames of such scientific concept, the inertia forces cease to be a "special" class of forces, to which the "action and reaction" law cannot be applied.

It follows from (14) that inertia appears only in the case of accelerated motion of a charged particle relative to physical vacuum. In the case of uniform and rectilinear motion of the particle relative to physical vacuum inertia does not appear. This corresponds to Newton first law.

4.2. Discussion

Let us discuss the issue of usability of a frame of reference related to physical vacuum. Since physical vacuum seems to be as a continuous medium, in which "currents" and "deformations" may take place, it is clear that it is impossible to associate a single frame of reference to it and accept this frame of reference as absolute. But it is always possible to introduce and apply a conditionally motionless "local" frame of reference, in which a sufficiently large volume of physical vacuum stays practically motionless at least in one of the directions.

The above-described notion of mass determines its inertial properties only. However, the concept of physical vacuum opens the way to explanation of gravitation. It is shown in monograph [27] that one and the same physical process represents a reason for inertia and gravitation – namely, interaction of charged particles with accelerated fluxes of physical vacuum. And it is not important, which of the objects of interaction is regarded to be in motion and which is considered to be conditionally motionless. If we assume that there are radial accelerated fluxes of physical vacuum close to stars and planets, then the reason behind the gravitation becomes obvious. When using this concept, it becomes possible to give natural explanation to the issue of equivalence of inertial mass and gravitational mass - they are equivalent because they are preconditioned by one and the same physical phenomenon.

4.3. Result

A conclusion can be drawn that the phenomena of inertia and gravitation are equally explained by the interaction of charged particles with physical vacuum in the course of their relative accelerated motion.

5. Electromagnetic Field of Charged Particle

5.1. Theory

As follows from the results obtained and described above, mechanical phenomena and values are connected with electrodynamics that describes the state and evolution of the vacuum medium. Let us advert to electrodynamic values with the aim to clarify their characteristics and possible interpretations.

The electrical field of a conditionally motionless charged particle is spherically symmetrical. It is completely determined by scalar potential. If a charged particle is in motion within a chosen frame of reference, magnetic field also is generated around it. This field is characterized by electrodynamic vector potential $\boldsymbol{A}$. 4-vector $(\boldsymbol{A},\phi/c)$ can be adopted as the main characteristic of an electromagnetic field of moving charge.

According to Helmholtz theorem [30], any physical field (that is unlimited in space) has two components: potential component and vortex one. It us usually considered that the potential component of the electromagnetic field is fully determined by scalar potential ϕ , and this is why vector potential is deemed to be purely vortex. It is shown in [12-15] that such an approach leads to the loss of the physically substantial part of the field of moving charged particle. In the general case, electrodynamic vector potential should be presented as a superposition of two components:

$$\boldsymbol{A} = \boldsymbol{A}_r + \boldsymbol{A}_g , \tag{15}$$

where

$$\boldsymbol{A}_r = \boldsymbol{A}_{rot}$$

- is the vortex (solenoidal) component,

$$\boldsymbol{A}_g = \boldsymbol{A}_{grad}$$

- is the potential component.

Hence it is possible to put down the following:

$$\nabla \times \boldsymbol{A} = \nabla \times \boldsymbol{A}_r = \boldsymbol{B}, \tag{16}$$

$$\nabla \cdot \boldsymbol{A} = \nabla \cdot \boldsymbol{A}_g = -B^*, \tag{17}$$

where $\boldsymbol{B}$ – is the vector of vortex magnetic field induction, B^* – scalar function that characterizes the potential component of the magnetic field.

The last component is usually called scalar magnetic field (SMF). It is usually excluded with the use of Coulomb and Lorentz gauges. The theory that takes into account both components of the magnetic field is called generalized electrodynamics [12-15].

Within the frame of reference K_0 that accompanies the charged particle, there is only electrical field:

$$\boldsymbol{E}_0 \neq 0, \quad \boldsymbol{B}_0 = 0, \quad B_0^* = 0.$$

Correspondingly, for the potentials we have:

$$\phi_0 \neq 0, \quad \boldsymbol{A}_0 = 0.$$

We need to determine the 4-potential components and characteristics of electromagnetic field in a conditionally motionless frame of reference *K*, relative to which the particle moves rectilinearly with velocity $\boldsymbol{v}$. We will use the following notations in the frame of reference *K*:

$$\boldsymbol{E} \neq 0, \quad \boldsymbol{B} \neq 0, \quad B^* \neq 0 \text{ и } \phi \neq 0, \quad \boldsymbol{A} \neq 0.$$

After using Lorentz transformations in the SI system [31] for a positive particle we have:

$$\phi = \gamma(\phi_0 - \boldsymbol{v} \cdot \boldsymbol{A}), \tag{18}$$

$$\boldsymbol{A} = \boldsymbol{A}_0 - \gamma \frac{\boldsymbol{v}}{c^2}\phi_0 + (\gamma - 1)\frac{\boldsymbol{v}}{v^2}(\boldsymbol{v} \cdot \boldsymbol{A}_0), \tag{19}$$

where $\gamma = \left(1 - v^2/c^2\right)^{-2}$.

In the case of rectilinear and uniform motion of particle, its field in *K* has the following characteristics:

$$\begin{aligned} \boldsymbol{E} &= \gamma[\boldsymbol{E}_0 - \boldsymbol{v} \times (\nabla \times \boldsymbol{A}) - \boldsymbol{v} \cdot \nabla \boldsymbol{A}] = \\ &= \gamma\left(\boldsymbol{E}_0 - \boldsymbol{v} \times \boldsymbol{B} + \boldsymbol{v} \cdot B^*\right), \end{aligned} \tag{20}$$

$$\boldsymbol{B} = \frac{\gamma}{c^2} \boldsymbol{v} \times \boldsymbol{E}_0 , \tag{21}$$

$$B^* = \frac{\gamma}{c^2} \boldsymbol{v} \cdot \boldsymbol{E}_0 . \tag{22}$$

Galilean transformations are used at low velocities:

$$\boldsymbol{E} = \boldsymbol{E}_0 - \boldsymbol{v} \times \boldsymbol{B} + \boldsymbol{v} \cdot B^* , \tag{23}$$

$$\boldsymbol{B} = \frac{1}{c^2} \boldsymbol{v} \times \boldsymbol{E}_0 = \frac{\mu_0 q}{4\pi} \frac{\boldsymbol{v} \times \boldsymbol{r}}{r^3} , \tag{24}$$

$$B^* = \frac{1}{c^2} \boldsymbol{v} \cdot \boldsymbol{E}_0 = \frac{\mu_0 q}{4\pi} \frac{\boldsymbol{v} \cdot \boldsymbol{r}}{r^3} . \tag{25}$$

Formula (24) represents Bio-Savart Law (Laplace’s law), while (25) represents an analogue of the same law for SMF. The distribution of vector and scalar magnetic fields of a particle in motion is determined by formulas (24) and (25). Fig. 1 shows a schematic generalized magnetic field of a positively charged particle in motion.

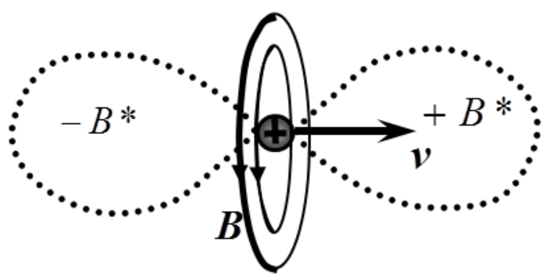

Fig. 1. *Schematic representation of magnetic field of a positively charged particle in motion.*

If a positively charged particle moves along axes *Ox* $(v << c)$, the vortex magnetic field in spherical coordinates (r, φ, θ) is represented by function:

$$B(r, \varphi, \theta, t) = \frac{\mu_0 q v}{4\pi r^2} \sqrt{\sin^2\theta \sin^2\varphi + \cos^2\theta} . \tag{26}$$

Distribution of SMF takes place according to law:

$$B^*(r,\varphi,\theta,t) = \frac{\mu_0 q}{4\pi}\frac{v}{r^2}\sin\theta\cos\varphi\ . \tag{27}$$

Here $r = r(t)$ – is the distance from the center of moving particle to a point in space, in which the field is determined. Angles θ and φ - are also functions of time. Therefore, magnetic field of a lone charged particle in motion is always nonstationary.

It follows from (25) and (27) that in the plane going through the particle center orthogonally to the vector of its motion velocity

$$B^*\left(r,\frac{\pi}{2},\theta,t\right) = 0\ .$$

Ahead of the positive particle in motion, function B^* has positive sign, while behind the particle SMF has negative sign (Fig. 1). For a negative particle in motion, polarity of SMF will be reverse.

Time derivative $\partial B^*/\partial t$ has a dimension of charge density. The phenomenon of vortex-free electromagnetic induction is theoretically and experimentally substantiated in [12] and [15] – nonstationary SMF generates potential electrical field. The corresponding law is written down in the following form:

$$\nabla\cdot\boldsymbol{D} = \frac{\partial B^*}{\partial t},$$

where D – vector of electric induction. In other words, a point in space, in which nonstationary SMF is created within the chosen frame of reference, is similar to the point electric charge. We will call it quasi-charge.

It turns out that charged particle in motion additionally acquires properties of electric dipole. A positive quasi-charge arises ahead of the positively charged particle in motion (in the direction of its motion), while behind it – negative.

For a negatively charged particle, the sign for the velocity should be changed to the opposite in formulas (18)-(25). In this case the signs of dipole quasi-charges also will change to the opposite ones.

5.2. Discussion

Thus, the electric field of a moving charge has a complex configuration in the frame of reference *K*. The electric field represents a superposition of Heaviside's ellipsoidal field [1] and electric dipole field. Since the quasi-charges that make up the dipole have different signs, the potential energy of their interaction is negative. It follows from here that negative sign must be attributed to SMF energy. Due to this reason, V. D. Andreev [32] proposed to describe SMF as an imaginary function.

If we use electrical fields of such complex configuration when studying the interaction of mobile charges, mathematical expressions will be lengthy. That's this problem is usually presented in a structured form – namely, superposition of a spherically symmetric (Coulomb) electric field and superposition of an additional electrical field that does not spherical symmetry are subjected to consideration. This last component of the electrical field is called the magnetic field. As is well-known, it depends on the choice of the frame of reference.

Let's analyze an electron in an accompanying frame of reference K_0. It is considered to be motionless, while the vacuum medium flows around it with a constant velocity. In this case the electron experiences a "vacuum wind". Hence, its electric field is deformed, and magnetic field appears. To detect it, another trial charge is needed. Let's place it motionless relative to the electron in K_0. The trial charge also experiences "vacuum wind", and its magnetic field appears. The overall result of electric and magnetic interactions of electron and trial charge will be expressed by usual Coulomb force. Hence, it won't be possible to detect magnetic field in this experiment even if the charges are located in a flux of vacuum medium.

Let's change the conditions of experiment. Let the electron still be in an accompanying frame of reference K_0, while the trial charge is located motionlessly in the frame of reference K_0 connected with the local flux of physical vacuum. Such a frame of reference is usually called inertial. If K_0 moves translationally and uniformly relative to *K*, it is also inertial. The trial charge does not feel the "vacuum wind", and its electric field is not deformed. In this case within any of the frames of reference K_0 or *K* interaction of a mobile charge with the motionless charge takes place. The trial charge has a spherically symmetric (Coulomb) field, while the electric field of electron is deformed by the "vacuum wind". The interaction force of these charges is different from Coulomb force. Hence, it is possible to determine the energy of interaction between electron and physical vacuum in this experiment. This is the energy of the magnetic field. It can be deduced from the given imaginary experiments that magnetic field can only be detected only in the case of relative motion of the main and trial charges. Besides, both charges should be connected with inertial frames of reference.

Thus, the phenomenon of magnetic field itself proves the existence of physical vacuum. If one imagines a charged particle moving through absolute vacuum, it would be impossible to specify a factor that leads to distortion (described above) of the electric field of this particle. Of course, relativistic effect for a lone electron is manifested in accordance with (1), although in the case of charge-drift velocity of several millimeters per second, it is very small. Integral expression for this effect for the current in a conductor can only give an idea about the vortex magnetic field. Relativistic effect is incapable of describing the second component of the magnetic field – namely, potential component.

5.3. Results

1. Magnetic field emerges in the course of charged particle motion relative to vacuum medium.

2. Magnetic field of a lone charge has two components – vortex (vector) component and potential (scalar) component.
3. Energy of scalar magnetic field has negative sign.

6. Energy of Electron's Magnetic Field

6.1. Theory

Using (26) let's write down expression for energy density distribution of the vector magnetic field of mobile electron:

$$w_B = \frac{B^2}{2\mu_0} = \frac{\mu_0}{2}\left(\frac{qv}{4\pi}\right)^2 \cdot \frac{\left(\sin^2\theta\sin^2\varphi + \cos^2\theta\right)}{r^4}, \quad (28)$$

We assume that limits of integration in radial direction are from r_e to ∞. Using spherical coordinates(r,φ,θ), we derive energy of vector magnetic field:

$$W_B = \frac{\mu_0 q^2 v^2}{32\pi^2}\int_0^{\pi}\left(\sin^2\theta\sin^2\varphi + \cos^2\theta\right)d\theta\int_0^{2\pi}d\varphi\int_{r_e}^{\infty}\frac{1}{r^2}dr = \frac{\mu_0 q^2 v^2}{12\pi r_e}. \quad (29)$$

Using expression (7) for particle mass at $l = 2r_e$, we obtain:

$$W_B = \frac{\mu_0 q^2 v^2}{24\pi r_e} = \frac{4}{3}\frac{mv^2}{2} = \frac{4}{3}K. \quad (30)$$

This result is known under the name "problem 4/3" [1]. The energy of vortex magnetic field exceeds kinetic energy of a particle.

Let's calculate the energy of scalar magnetic field of this particle using (27). As is shown above, this energy is negative:

$$W_{B^*} = -\int_V \frac{B^{*2}}{2\mu_0}dV = -\frac{\mu_0 q^2 v^2}{32\pi^2}\int_0^{\pi}d\theta\int_0^{2\pi}d\varphi\int_{r_e}^{\infty}\left(\frac{\sin\theta\cos\varphi}{r^2}\right)^2 r^2\sin\theta dr.$$

Taking into account (7), we obtain the following value:

$$W_{B^*} = -\frac{\mu_0 q^2 v^2}{48\pi r_e} = -\frac{1}{3}\frac{mv^2}{2} = -\frac{1}{3}K. \quad (31)$$

After adding (30) to (31), we derive energy of generalized magnetic field, which is exactly equal to kinetic energy of electron:

$$W_{B+B^*} = \frac{4}{3}K - \frac{1}{3}K = K.$$

The same result can be obtained without using characteristics of magnetic field intensity B and B^*. Let particle having charge q and radius r_e accelerates in the frame of reference K connected with local vacuum medium. We restrict ourselves to the case when final velocity is significantly less than light velocity. The interaction of moving particle with the medium is determined by vector potential:

$$\boldsymbol{A}(t) = \frac{\mu_0 q \boldsymbol{v}(t)}{4\pi r_e}. \quad (32)$$

Distance r_e is used here because the action of medium upon the particle takes place on its spherical surface. We believe that spherical particle moves translationally. Therefore, when describing its motion, one can use differential equation for particle dynamics. In the case of acceleration in an external medium a particle is subjected to external decelerating action (force of inertia):

$$\boldsymbol{F} = -q\frac{d\boldsymbol{A}}{dt}. \quad (33)$$

The force that accelerates a particle is characterized by the same modulus, though having an opposite sign:

$$\boldsymbol{F} = q\frac{d\boldsymbol{A}}{dt}. \quad (34)$$

In the case of particle deceleration $d\boldsymbol{A}/dt < 0$, that's why signs of forces in equations (33) and (34) will be changed to opposite ones.

Let's imagine (34) as momentum theorem for particle:

$$\boldsymbol{F}dt = qd\boldsymbol{A}.$$

The right side represents differential for momentum of particle:

$$d\boldsymbol{Q} = qd\boldsymbol{A}.$$

where $\boldsymbol{Q} = m_0\boldsymbol{v}$.

Taking (32) into account, let's write down:

$$d\boldsymbol{Q} = \frac{\mu_0 q^2}{4\pi r_e}d\boldsymbol{v}.$$

After multiplying scalarly both sides of this equation by $v/2$, we obtain differential of kinetic energy (in the left side):

$$dK = \frac{\mu_0 q^2}{4\pi r_e}\frac{\boldsymbol{v}}{2}\cdot d\boldsymbol{v}.$$

As a result of integration (taking into account (8)) we derive the following expression:

$$K = \frac{\mu_0 q^2}{8\pi r_e}\frac{v^2}{2} = \frac{m_0 v^2}{2}.$$

As can be seen, with such an approach one does not encounter any problem with energy relationship because vector A completely takes into account the interaction of moving charged particle with vacuum medium.

6.2. Result

Problem 4/3 is solved when mass is defined as purely electromagnetic phenomenon taking into account vortex and potential components of magnetic field.

7. Conclusion

It is impossible to visually observe elementary particles and fields (related to these particles). That's why the problem of modeling particles and fields becomes of conceptual importance. Evolution of our ideas and notions about microcosm is directly connected with the development of such models and evaluation of their adequacy at each stage of knowledge gaining. Therefore scientific discussion on issues related to this problem is always important.

One of the possible concepts (the roots of each are connected with the names of Newton, Faraday and Maxwell) is substantiated and developed in this article. It forms a unified scientific platform for mechanics and electrodynamics. It can be stated that mechanics represents macroscopic generalization of electrodynamics of physical vacuum [33]. This thesis enables to work out an adequate model for electron and logically substantiate the following results:

1. Electron mass has solely electromagnetic nature.
2. Inertia and gravitation arise due to interaction of charged particle with vacuum medium in the course of their relative accelerated motion.
3. Magnetic field emerges when a charged particle moves relative to vacuum medium. The energy of magnetic field of a sole charged particle is equal to to kinetic energy of this particle.

Further development of relationships and analogies between mechanics and electrodynamics on the basis of adequate models of microcosm would allow natural science to move to a totally new level.

The authors are grateful to professor V. D. Andreyev for his helpful advices given in the course of preliminary discussion of research results.

References

[1] Feynman R., Layton R, Sands M.: Feynman Lectures on Physics. Volume 6: Electrodynamics. Translated from English (edition 3). Mir, Moscow (1977).

[2] Thomson J. J.: On the Electric and Magnetic Effects produced by the Motion of Electrified Bodies. Philosophical Magazine, 5 11 (68): 229–249. 10.1080/14786448108627008

[3] Maxwell J.: Treatise on Electricity and Magnetism. In two volumes. Nauka, Moscow (1989).

[4] Stokes G.G. On some cases of fluid motion on Internet Archive. Transactions of the Cambridge Philosophical Society 8 (1): 105–137 (1843).

[5] Mitkevich V.F.: "Physical" action at a distance. Proceedings of the Russian Academy of Science. Series VII. Division of mathematical and natural science, 1391–1409 (1933). http://books.e-heritage.ru/book/10081581

[6] Zhilin P. A.: Reality and Mechanics. Proceedings of XXIII school-seminar "Analysis and synthesis of nonlinear mechanical oscillating systems". IP Mash of Academy of Science. St. Petersburg, pp. 6-49 (1996). http://teormeh.spbstu.ru/Zhilin_New/pdf/Zhilin_Reality_rus.pdf

[7] K. J. van Vlaenderen, Waser A.: Generalization of classical electrodynamics to admit a scalar field and longitudinal waves. Hadronic Journal 24, pp. 609-628 (2001).

[8] Woodside D.A.: Three-vector and scalar field identities and uniqueness theorems in Euclidean and Minkowski spaces. American Journal of Physics, Vol.77, № 5, pp.438- 446, (2009).

[9] Arbab A.I., Satti Z. A.: On the Generalized Maxwell Equations and Their Prediction of Electroscalar Wave. Progress in physics, v.2.- pp.. 8-13 (2009).

[10] Podgainy D.V., Zaimidoroga O.A.: Nonrelativistic theory of electroscalar field and Maxwell electrodynamics. http://arxiv.org/pdf/1005.3130.pdf

[11] Alexeyeva L. A.: Biquaternionic Model of Electro-Gravimagnetic Field, Charges and Currents. Law of Inertia. Journal of Modern Physics, 2016, 7, pp.435-444. http://dx.doi.org/10.4236/jmp.2016.75045

[12] Tomilin A.K.: Foundations of generalized electrodynamics. Internet-Journal of Saint Petersburg State Technological University "Mathematics at universities", №17 (2009). http://www.spbstu.ru/publications/m_v/N_017/frame_17.html

[13] Nefedov E.I.: Electromagnetic fields and waves. Learning Guide. Academia, Moscow (2014).

[14] Tomilin A.K.: The potential-vortex theory of electromagnetic waves. Journal of Electromagnetic Analysis and Applications, v.5, № 9. pp. 347-353 (2013). http://dx.doi.org/10.4236/jemaa.2013.59055

[15] Nikolaev G.V.: Modern Electrodynamics and Reasons for its Paradoxicality. Tverdynya Tomsk (2003). http://doverchiv.narod.ru/Nikolaev/Nikolaev_modern_electrodynamics.htm

[16] Misyuchenko I., Vikulin V.: Electromagnetic mass and solution for problem 4/3. http://electricaleather.com/d/358095/d/em43_1.pdf

[17] Rohrlich F.: The dynamics of a charged sphere and the electron. American Journal of Physics 65 (11): pp.1051–1056 (1997). 1997AmJPh..65.1051R , doi :10.1119/1.18719

[18] Schwinger J. Electromagnetic mass revisited// Foundations of Physics, 13 (3): pp. 373-383, (1983). 10.1007/BF01906185

[19] Fedosin S.G.: The Integral Energy-Momentum 4-Vector and Analysis of 4/3 Problem Based on the Pressure Field and

Acceleration Field. American Journal of Modern Physics. Vol. 3, №. 4, pp. 152-167 (2014).

[20] Fedosin S.G.: 4/3 Problem for the Gravitational Field. Advances in Physics Theories and Applications. Vol. 23, pp.19 – 25 (2013).

[21] Lorentz G.A.: The theory of electrons and its application to the phenomena of light and heat radiation. Moscow (1956)

[22] Kiryako A.G.: Theories of origin and generation of mass. http://electricaleather.com/d/358095/d/massorigin.pdf

[23] Daywitt W.C.: A Planck Vacuum Pilot Model for Inelastic Electron-Proton Scattering. Progress in Physics. Vol. 11 (2015), pp.308-310.

[24] Artsimovich L.A.: Elementary Physics of Plasma. Moscow (1963).

[25] Sarapulov F.N. Calculation of parameters for circuits of electro-technological installations. Learning Guide. Ekaterinburg (1999). http://window.edu.ru/resource/485/28485/files/ustu092.pdf

[26] Tomilin K.A.: Planckian values. 100 years to quantum theory. History, Physics. Philosophy: Proceeding of International Conference. NIA-Priroda, Moscow, pp. 105—113 (2002).

[27] Parcell E.: Electricity and Magnetism. Berkeley course of physics. V..2. Nauka, Moscow (1975).

[28] Chang D.C., Lee Y.-K.: Study on the Physical Basis of Wave-Particle Duality: Modeling the Vacuum as a Continuous Mechanical Medium. Journal of Modern Physics, 6, pp. 1058-1070 (2015). http://dx.doi.org/10.4236/jmp.2015.68110

[29] Misyuchenko I.: Last Secret of God. St. Petersburg (2009). http://electricaleather.com/d/358095/d/poslednyaya-tayna-boga.pdf

[30] Helmholtz H.: About integrals of hydrodynamic equations, which correspond to the vortex motion. Crelles J. 55, 25 (1858).

[31] Fock V.A.: Theory of space, time and gravitation., Moscow (1955).

[32] Andreev V.D.: Selected problems of theoretical physics. Avanpost-Prim, Kiev (2012). http://www.twirpx.com/file/1135625/

[33] Nikolaev G.V.: Electrodynamics of physical vacuum. New concepts of physical world. Tomsk (2004). http://electricaleather.com/d/358095/d/nikolayevg.v.elektrodinamikafizicheskogovakuuma.pdf