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Reynolds Number in Electrodynamics

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Abstract

*The electric charge definition is formulated. The refined formula of the electric charge non-invariance is given. The electric charge momentum conservation law was obtained. The concept of "the char-ged particle spin" is clarified. The angular momentum conservation law for electric charge was obtained. The frequency moment definition (the magnetic moment analog) is formulat-ed in gravidynamics. The formula for the kinetic energy of the translational motion of an electric charge was constructed. Steiner's theorem for electrodyna-mics was formulated. The rotational mo-tion dynamics equation was constructed for electric charge. The formula for the kinetic energy of the rotational motion of an electric charge was constructed. A Planck formula analog for the mag-netic field was obtained. Formula for the interval s between two events was constructed in the elec-tric charge space. The author proposes the Coulomb's law application limit explanation. A parallel study possibility justification of black holes and atomic nuclei is given. A Reynolds number analog for electromagnetism was obtained: Ř=ρ e v D/**H**=I D/ (s H) =4I/ (π D H). The experiments result on finding the Reynolds number in electrodynamics are given.*

Keywords: The Angular Momentum of Electric Charge, The Rotational Motion Dynamics Equation for Elec-tric Charge, A Planck Formula for the Magnetic Field, Reynolds Number in Electrodynamics.

Electric charge is a body acceleration measure when only an electric field is applied to the body (it's assumed that the body consists only of an electric charge, that's it hasn't mass).

To unambiguous interpret of the terms used in this work the author considers it necessary to make some remarks about ter-minolo-gy. Just as in the electric charges interaction field there are electric, magnetic and electromagnetic fields, in the masses interaction field there are gravitational, fre-quency (the author suggests using this term) and gravifrequency (again, the author suggests using this term) fields. The term "gravitational field" is used in the conventional sen-se (field with a strength a, which is the acceleration). The frequency field is the field of the angular velocity ω. The term "angular veloci-ty field" may be replaced with the term "frequency field". And the gravifre-quency field is the same set of gravitational and frequency fields as the electro-magnetic field is the set of electric and magnetic fields. It would be more accurate to speak of a gravifrequency field equations system but not of the gravitational field equations system, and not of gravitational waves, but of gravifrequency waves.

After Maxwell's electrodynamics united in one theoretical sche-me the phenomena of electricity, magnetism and optics on the electromagnetic field concept basis, it was hoped that the field con-cept should be the foundation of a future unified theory of the physical world [1].

Einstein attempted to construct a unified field theory in which gravitational and electromagnetic fields are interpreted only as components or manifestations of the same unified field [2].

The author believes that there is some set of similar formulas (but not identical) that allows you to describe the phenomena of electrodynamics and gravidynamics. Subsequently, it will prob-ably be possible to add hydrodynamics, thermodynamics, and other sections of physics. But the same struc-ture of these formulas (and the symbols included in them) will imply completely different physical quantities, characteristic of one or another section of physics.

According to Okun L. B. the simplest variants realizing the idea of grand unification assume that there are no new fundamental forces up to colossal energies of the order of 1015 GeV [3].

This work considers the frequency interaction, which is a new fundamental interaction.

Introduction

The behavior of electric charges in the absence of mass has long been a topic of conceptual interest, especially in the search for unified theories that interconnect electrodynamics and gravitation. Building on the framework of classical field theories and recent theoretical propositions, this study investigates a novel perspective on electric charge dynamics by introducing new analogies and formulations rooted in both electrodynamics and a proposed "gravidynamics" domain. The exploration of a Reynolds number analog in electrodynamics, inspired by fluid dynamics, provides a new dimension for understanding the interactions between current, field strength, and electric charge density in conductive systems.

This work aims to refine the foundational understanding of electric charge behavior, particularly in terms of momentum and angular momentum conservation, energy expressions, and rotational dynamics. By extending classical mechanical principles—such as Steiner's theorem and kinetic energy equations—into the realm of electric charge dynamics, the study offers a compelling set of formulations that may serve as stepping stones for a broader theoretical synthesis.

In this context, the paper also introduces the concept of a frequency interaction as a potential new fundamental interaction. The results from experiments on the Reynolds number in electrodynamics are expected to contribute not only to theoretical physics but also to practical applications involving magnetic fields and electrical conductivity. The work further seeks to draw parallels between black hole physics and atomic nucleus conditions, suggesting potential cross-disciplinary insights in high-energy and astrophysical research.

Formulation of the Problem

The purpose of this work is to generalize and specify some concepts of electrodynamics and gravidynamics, as well as to present the results of experiments to determine of the Reynolds number in electrodynamics.

Results

the momentum conservation law and the angular momentum conservation law are formulated for electric charge; the concept of "the charged particle spin" is clarified; Steiner's theorem for electrodynamics was formulated; the Planck formula analog was obtained for the magnetic field;

formula for the interval s between two events was constructed in the electric charge space; the rotational motion dynamics equation was constructed for electric charge; the Reynolds number analog values were experimentally obtained in the current range from 20 mA to 500 mA.

Discussion

Electric Charge, Electric Charge Non-invariance, Charged Particle Spin, Frequency Moment

The Lagrange function L for the electric charge e in the electromagnetic field can be written in the form [4].

$$L = -\mathrm{mc}^2\sqrt{1-\frac{v^2}{c^2}} + e(A\cdot v) - e\phi \qquad (1)$$

Let's transform the Lagrange function for the electric charge space.

By the concept of "electric charge space" the author understands everything that exists or happens without the presence of masses. That's all bodies must be of zero mass and processes or phenomena must occur with bodies having zero mass.

Since in gravifrequency interactions the vector potential
Ag = **v**, and **v** = **a**×**t**,
then in electric charge space [5].

Ae = **E**×**t**,
where E is electric field strength.

And when the vector potential $\mathbf{A}_e$ is multiplied by the electric charge e, the formula for the electric charge momentum pe is formed.

$$\mathbf{p}_e = \mathbf{e}\,\mathbf{A}_e$$

It should be noted that pe is not a part of the fictitious momentum ***P***, as indicated in the work, but of the real one [6]. There is no fiction here. The electric charge momentum $\mathbf{p}_e$ is a part of the generalised momentum ***P***, which is equal to the sum of the mechanical momentum (mv) and of the electric charge momentum ($\mathbf{p}_e$). And hence, there is no forgery or falsification here.

In work it is stated: Newton's law of world gravitation has not yet had an electromagnetic explanation [7]. It should be noted that it and cannot receive an electromagnetic explanation. Our knowledge of mass and electric charge (as well as mass and electric charge themselves) go parallel streets. The kind of laws on one street coincide with the kind of laws on the other street. But the basis on each street is different, on one street it is mass and on the other street it is electric charge. Therefore, it is incorrect to explain any effects of gravitation (not only the Newton's law of world gravitation) with the help of electric charge. How can a tomato salad have a cucumber explanation?

It's impossible to explain mass through electric charge and vice versa. Gravi-frequency phenomena are explained by the presence and motion of masses, and electromagnetic phenomena are explained by the presence and motion of electric charges.

For the electric charge space (given that E = λe and c2 ↔ λ the Lagrange function will be in the form

$$L_e = -e\lambda\sqrt{1-\frac{Etv}{\lambda}} + e(A_e \cdot v) - e\phi_e \quad (2)$$

where λ is constant, $\lambda \approx 106$ V (Lunin, 2006); ϕe is electric field potential [8-9].

The refined formula of electric charge non-invariance was applied in formula (2),

e = e_0/√(1-Etv/λ).

Then the action Se for an electric charge in an electromagnetic field can be written as follows

$$S_e = \int_{t_1}^{t_2} (-e\lambda\sqrt{1-\frac{Etv}{\lambda}} + e(A_e v) - e\phi_e)\mathrm{d}t$$

Let's write the expression for the electric charge momentum pe located in a constant electric field with strength E = (Ex, 0, 0). Notice the body is in the electric charge space [8].

$\mathbf{p}_e = e\,\mathbf{E}\,t$,

where t is the existence time of the body in the electric field. There is the electric field only.

Then we can write an expression for the force

$(\mathrm{d}\boldsymbol{p}_e)/\mathrm{d}t = \boldsymbol{F}_e$, where $\boldsymbol{F}_e = e\,\boldsymbol{E}$.

In the absence of external forces (Fe = 0) we can write

$(\mathrm{d}\boldsymbol{p}_e)/\mathrm{d}t = 0$

It's possible to formulate the electric charge momentum conservation law: the electric charge momentum (located in a system of electric charges) is constant for a closed system.

It should be noted that the electron spin needs to be specified. The electron has mass and electric charge. Each of these quantities is responsible for its part (its contribution) to the total spin. And since both parts are measured in the same units (J·s), they appear as one common spin.

This remark about spin applies to all particles that have mass and electric charge.

The same can be said about the orbital momentum (mechanical and electric) of objects that have a mass and electric charge. The total momentum will consist of the sum of the mechanical momentum (mv) and the electric charge momentum (e E t).

Let's compare the expressions for the momentum of the electron in an atom as the possessor of mass and as the possessor of electric charge [5].

$m\boldsymbol{v}/(e\boldsymbol{E}t) \quad (3)$

Given that v = at, we can rewrite the previous expression as

$mat/(e\boldsymbol{E}t) = m\boldsymbol{a}/(e\boldsymbol{E})$

In the right part of the equation we see the relation of two forces: centripetal and Coulomb forces. In the problem under consideration, they are equal when moving in a circle. So, the relation (3) is equal to 1. Consequently, the mechanical momentum (mv) is equal to the electric momentum (eEt). And hence the momentum of mechanical momentum (mvr) is equal to the momentum of electrical momentum (eEtr).

Then, comparing mechanical kinetic energy (mv2/2) and electric kinetic energy (eEtv/2) we can see that they are equal. This statement is truer than in previous works.

By analogy with mechanics let's write the expression for the point electric charge e angular momentum Le (in the electric charge space) relatively to the point O as a vector product

$\boldsymbol{Le} = [\mathbf{r} \times \boldsymbol{p}_e]$,

where r is the radius-vector from point O to the point charge e.

$\boldsymbol{Le} = \boldsymbol{e}\,[\boldsymbol{r} \times \boldsymbol{E}]\,\boldsymbol{t}$

$(\mathrm{d}\boldsymbol{L}_e)/\mathrm{d}t = [\mathrm{r} \times \boldsymbol{F}_e]$

$(\mathrm{d}\mathbf{L}_e)/\mathrm{d}t = \boldsymbol{M}_e$,

And we got the expression for the forces moment Me relatively to the same point O.

It's possible to formulate the angular momentum conservation law for electric charge: the electric charge angular momentum Le is constant for a closed system (that's $\boldsymbol{M}_e = 0$).

Let's find a physical quantity that is the magnetic moment analog pm. Let's write down the formula for the magnetic moment pm

$\boldsymbol{p}_m = IS\boldsymbol{n}$.

By analogy with the electric charge space, let's call the next expression the frequency moment $\boldsymbol{p}_\omega$

$\boldsymbol{p}_\omega = I_{mas}\ S\ \mathbf{n}$,

where Imas is mass current flowing along the circuit;

S is the area covered by this contour.

The mass current Imas should be understood as the consumption Qmas of mass m, that's the mass m change per unit time t

$I_{mas} = Q_{mas} = \Delta m/\Delta t$

Kinetic Energy and Steiner Theorem for Electric Charge

By analogy with mechanics, we can write an expression for the kinetic energy Ek of the translational motion of an electric charge e

$E_{ke} = e \times \boldsymbol{E} \times t \times v\ /2$

(understanding that $\boldsymbol{E}\times t$ is an analog of $\boldsymbol{a}\times t = v$)

We can write a general expression for kinetic energy

$Ek = \boldsymbol{pv}/2$

If the body has both mass and electric charge, the total kinetic energy will be as follows

$E_k = E_{kg} + E_{ke} = \boldsymbol{p}_g\boldsymbol{v}/2 + \boldsymbol{p}_e\boldsymbol{v}/2 = m\boldsymbol{v}v/2 + e\boldsymbol{E}t\boldsymbol{v}/2 = (mv + e\boldsymbol{E}t)\boldsymbol{v}/2 = \boldsymbol{pv}/2$

And not only mass, but also the electric charge of the body (particle) is responsible for the amount of energy in the body (particle). And when calculation the total energy Etot of a body (particle) it will be necessary to consider the formula [8].

$E = e\lambda$

By analogy with mechanics, we define the electric charge e inertia moment Ie relatively to a given axis as the value equal to the product of the electric charge e and the distance r square to the considered axis

$$I_e = e\, r^2$$

It’s possible to formulate the Steiner theorem analog (for electric charge). The electric charge e inertia moment Ie relatively to an arbitrary axis is equal to its moment Ic of inertia relatively to a parallel axis passing through the electric charge center C added with the product of the electric charge e and the distance a square between the axes

$$I_e = I_c + e\, a^2 \qquad (4)$$

In mechanics

$$\boldsymbol{L} = I\, \boldsymbol{\omega},$$

where $\boldsymbol{L}$ is the angular momentum;
I is the inertia moment;
ω is the angular velocity.

Passing to the electric charge space, we replace ω by magnetic induction $\boldsymbol{B}/2$ [5].

By analogy we can write

$$\boldsymbol{L}_e = I_e\ \boldsymbol{B}/2$$

where Le is the angular momentum of the electric charge.

It's possible to construct the rotational motion dynamics equation of electric charge e relatively to a fixed axis.

In mechanics

$$\boldsymbol{M} = I\, d\boldsymbol{\omega}/dt,$$

where M is the force moment [10].

Passing to the electric charge space, we can write the rotational motion dynamics equation of electric charge

$$\boldsymbol{M}_e = 1/2 I_e\ d\boldsymbol{B}/dt,$$

where $\boldsymbol{M}_e = [\boldsymbol{r} \times \boldsymbol{F}_e] = [\boldsymbol{r} \times (e\,\boldsymbol{E} + e\,\boldsymbol{v}\,\boldsymbol{B})]$

It's possible to construct a formula for the kinetic energy of the rotational motion in the electric charge space. The kinetic energy Ek of the rotational motion in mechanics is calculated by the formula

$$E_k = I\, \omega^2/2$$

By analogy let's write down the formula for the kinetic energy Eke of the rotational motion in electric charge space. In the last formula we replace ω by B/2 (but only for one ω). Then

$$E_{ke} = I_e\, \boldsymbol{\omega} \cdot \boldsymbol{B}/4$$

Planck Formula, Interval, Uncertainty Ratio

In the electric charge space, it’s possible to construct the Planck formula analog, in which the magnetic induction B will participate together with some constant. Let's write down the Planck formula

$$E = \hbar\, \omega$$

Let's replace ω with the magnetic induction B. In this case, it will be necessary to replace and ħ with other constant

$$E = const \times \mathbf{B}/2$$

From this it can be seen that if ħ represents a certain value of the angular momentum in the Planck formula, then the constant represents a certain (constant) minimum value of the magnetic moment in the last formula. Let’s denote it by $\boldsymbol{p}_{m0}$. It’s highly likely that it will be the nuclear magneton.

Then

$$E = \boldsymbol{p}_{m0} \cdot \boldsymbol{B}$$

This is the Planck formula analog.

There is a formula for the interval s between two events [11]

$$s^2 = c^2\, t^2 - x^2 - y^2 - z^2$$

Let’s construct this formula analog in the electric charge space. c2 will be replaced by λ. In the expression t2 we pass to angular velo-city ($t = 2\pi/\omega$). And we will do it only for one time, and leave the second time t unchanged.

In the right-hand side of the equation, the first term will look like this $\lambda\, t\, 2\pi/\omega$. And now we replace $\boldsymbol{\omega}$ by $\boldsymbol{B}/2$. And we get the final formula for the interval se between two events in the electric charge space

$$s_e^2 = \lambda\, t\, (4\pi/B) - x^2 - y^2 - z^2$$

De Broglie wavelength λB = h/p [11]. In the electric charge space, it will look as follows

$$\lambda_{Be} = h/(eEt)$$

$$\lambda_{Be}/(2\pi) = \hbar/(eEt)$$

$$1/_{ke} = \hbar/(eEt)$$

$$eEt = \hbar\, k_e$$

$$p_e = \hbar\, k_e$$

Let's write the uncertainty ratio [11].

$$\Delta E \times \Delta t \geq \hbar$$

Considering that [8]

$$E = e\, \lambda,$$

we can write

$$\Delta\,(e\,\lambda) \times \Delta t \geq \hbar$$

$$\Delta e \times \Delta t \geq \hbar/\lambda$$

The shorter some state existence time or the time allotted for its observation, the less definitively it’s possible to speak about the electric charge of this state.

Let's think about the uncertainty ratio from a different point of view. Based on the three conservation laws (angular momentum, energy and momentum), we can formulate three postulates.

a) Postulate 1: there is a minimum value of angular momentum (it turned out to be equal to ħ).

This follows the Heisenberg uncertainty ratio.

$$\boldsymbol{r} \times \boldsymbol{p} \geq \hbar$$

Or in a more familiar form

$$\Delta \boldsymbol{r}\, \Delta \boldsymbol{p} \geq \hbar \qquad (5)$$

We obtained the known uncertainty ratio, but only did it in a simpler way (by introducing postulate 1).

b) Postulate 2: there is a minimum value of energy.

Let’s denote Emin - the minimum energy value. If ħ is a constant value, then there is a minimum value $\boldsymbol{\omega}_{min}$

$$E \geq \hbar\, \omega_{min}$$

$$E/\omega_{min} \geq \hbar$$

Or in a more familiar form

$$\Delta E\, \Delta t \geq \hbar \qquad (6)$$

The last expression can be obtained without the second postulate.

If p = E /c, then we can divide and multiply the left-hand side of expression (5) by c and obtain the expression (6).

c) Postulate 3: there is a minimum value of momentum.

$$p \geq p_{min}$$

If p = E /c, then $p \geq E_{min}/c$

$p \geq \hbar\, \omega_{min}/c$

$p/\omega_{min} \geq \hbar/c$

$$\Delta p\, \Delta t \geq \hbar/c \quad (7)$$

The last expression can be obtained without the third postulate. We can divide expression (6) by c (or divide expression (5) by c) and obtain the expression (7).

Note that it's not necessary to formulate all three postulates to obtain expressions (5) - (7). It's enough to formulate any of the three postulates and hence all three expressions (5) - (7) are obtained.

Interactions Comparison

The relation of the electric interaction force to the gravitational interaction force is calculated trivially in a school physics course.

$$\frac{F_{el}}{F_{gr}} = \frac{e^2}{m^2 4\pi\varepsilon_0 G} = 4.17 \times 10^{42} \quad (8)$$

where e and m are the electric charge and mass of electron;

ε0 and G are electric and gravitational constants.

A value of the same order is also given in [12].

It should be noted that so far, we can speak about the relation only of electric and gravitational forces, but not about the relation of electromagnetic and gravifrequency forces. Although in the future it will turn out that this relation is true for electromagnetic and gravi- frequency interaction as well.

Let's try to calculate the relation of magnetic forces to frequency forces. The interaction force between two magnets placed in parallel is calculated by the formula [13].

$$F_{mag\,par} = \frac{0.75\mu_0 p_1 p_2}{\pi r^4} \quad (8a)$$

where p1 and p2 are magnetic moments;
r is the distance between the magnets.

Let's calculate this force of interaction between two elementary magnets. As elementary magnets, let's take two electrons rotating along different circuits (S1 and S2) and with different rotation periods (T1 and T2)

$$F_{mag\,par} = \frac{0.75\mu_0 \frac{e}{T_1} S_1 \frac{e}{T_2} S_2}{\pi r^4}$$

For the electron, as a mass carrier, we can write by analogy the formula for the frequency interaction force

$$F_{\omega par} = \frac{0.75\mu_{0g} p_{\omega 1} p_{\omega 2}}{\pi r^4}$$

$$F_{\omega par} = \frac{0.75\mu_{0g} \frac{m}{T_1} S_1 \frac{m}{T_2} S_2}{\pi r^4}$$

$$\frac{F_{mag\,par}}{F_{\omega par}} = \frac{\mu_0 e^2}{\mu_{0g} m^2}$$

$$\mu_{0g} = 4\pi G/c^2 \text{ [5].}$$

Then $$\frac{F_{mag\,par}}{F_{\omega par}} = \frac{\mu_0 e^2 c^2}{4\pi G m^2}$$

$$\frac{F_{magpar}}{F_{gr}} = \frac{e^2}{m^2 4\pi\varepsilon_0 G} = 4.17 \times 10^{42}$$

We obtained an expression (9) that coincides completely with expression (8).

And only now we can assert that expression (8) characterises the relation of electromagnetic interaction to gravifrequency interaction.

In (Lunin, 2022) an analog of the Schwarzschild radius was found for the proton/electron/positron

$$r_\lambda = \frac{e}{4\pi\varepsilon_0 \lambda} \approx 10^{-15}\ \text{m}$$

We can say that the protons in the nucleus are in black hole conditions, that is, every atomic nucleus is a black hole. And for each atomic nucleus there will be a different value of the Schwarzschild radius analog, depending on the nucleus charge.

And although the nucleus is limited by the Schwarzschild radius, science has been able to 'break off' pieces of the nucleus. Drawing an analogy with black holes in the Universe, we can expect that it will be possible to 'tear off' pieces from black holes in the Universe. But for this purpose, it will be necessary more 'sharp and powerful knife'. The study of black holes in the Universe can help in the study of atomic nuclei and vice versa, and in quite different aspects.

Modern science denies the long-lived charged black holes existence possibility, believing that charges of the same sign will quickly scatter in different directions. However, it has to remember that under the black hole conditions, the Coulomb's repulsion forces become vanishingly small (a complete analogy with protons in a nucleus). Therefore, the charge in a black hole can persist for an arbitrarily long time.

Reynolds Number in Electrodynamics

Reynolds number R is calculated by the formula [14].

$$R = \frac{\rho v D}{\eta}$$

Let's replace the dynamic viscosity η by the magnetic field strength H [5].

Then $$\check{R} = \frac{\rho e v D}{H}$$

The current I in a conductor with cross-section s can be calculated by the formula [11]

I = ρevs,

where ρe = electric charge density;

s = πD2/4 (for a circular conductor).

Consequently ρev = I/s

Then there is the final expression

$Ř = \rho_e \boldsymbol{v} D/\boldsymbol{H} = 4I/(\pi D H)$.

Having obtained this formula, we can proceed to the experimental part.

Changing the magnetic field strength H, we will receive cor-res-ponding values of current I. And then we can calculate the Reynolds number in electrodynamics.

The solenoid was made of the ferromagnetic wire with a length of l = 1.1 m and a diameter of D = 0.2 mm. The wire was wound on a plastic tube with a diameter D = 50 mm.

The Reynolds number Ř values change from 1.27×10-3 to 2.54×10-3 when the current I change from 80 mA to 160 mA with the external magnetic field strength ***H*** = 400 A/m.

Measurements were taken at 5 mA intervals.

The current I change was stably observed at the external magnetic field strength ***H*** change from 400 A/m to 103 A/m. The current change was spasmodic, no large and very stable: from 90.2 mA to 90.1 mA (when the external magnetic field strength ***H*** reached the value of 700 A/m). A spasmodic change in resistance occurs appro-ximately at Ř ≈ 1.43×10-3.

The current changes remained the same when the magnetic field direction changed to the opposite.

The same change in current I (by 0.1 mA) is observed at such currents: 80 mA, 100 mA, 130 mA, 150 mA.

The magnetic field strength ***H*** change didn't lead to a current change at such currents: 60 mA, 50 mA or less. Perhaps this is due to the insufficient accuracy of the measuring equipment. The magnetic field strength ***H*** change also didn't lead to a current I change at such currents: from 200 mA to 500 mA.

The magnetic field strength ***H*** change did not lead to a current I change in experiments with a copper wire with the diameter D = 0.2 mm. The external magnetic field strength ***H*** changed so: from 400 A/m up to 1000 A/m.

The experiment was carried out in the current range (20÷500) mA.

Conclusions

It's desirable to carry out further experiments in this direction with more stable and powerful power sources, with more accurate measuring equipment, with different wire diameters and knowing the magnetic permeability μ of the wire.

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Data Availability Statement

The data that supports the findings of this study are available within the article [and its supplementary material].

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