On de Broglie Wave Nature

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ABSTRACT. The de Broglie wave phenomenon was studied in the framework of Lagrangean formulation of Relativistic Mechanics. The conclusion was made that the de Broglie wave of a particle is a relativistic phenomenon related to the field-dependent proper mass. The wave develops in a process of proper-to-kinetic mass transformation when the particle is given a momentum. The time-part of the 4-wave vector is related to the proper mass oscillation while the spacial part is due to the momentum; both parts can be treated in terms of virtual (longitudinal and scalar) photons characterizing excitation states of a mediating scalar field. It is shown that in Relativistic Mechanics with the variable proper mass both electromagnetic and gravitational force can be treated on the same footing: both are due to the same source that is, the proper mass. Consequently, the scalar mediating field provides a mechanism of unification of gravitational and electromagnetic forces. The concept of the unified divergence-free field is suggested, in which the real (transverse) photon represents a pure space-like particle while the neutrino is a pure time-like particle. In this connection, the parity problem is discussed.

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1 Introduction

The discovery of particle waves was made by Louis de Broglie in 1923-1924. It is usually assumed that the de Broglie waves are described by the Schroedinger equation. However, our study showed that the de Broglie wave phenomenon is essentially relativistic. De Broglie was never satisfied with probabilistic ("Copenhagen School") interpretation of Quantum Mechanics, and since 1924 he kept working on his own idea of a next-level ("double-solution") theory [1]. The physical meaning of the Schroedinger ψ-function as a probability amplitude of particle waves has been debated for decades, the nature of the De Broglie waves and so-called "entangled states" being the central issue (see, for example, [2, 3, 4]). The purpose of this work is to show that the de Brogli wave is essentially a relativistic phenomenon related to the proper-to-kinetic mass transformation; therefore, the question about causality versus probability interpretation of microscopic experiments is ill posed.

First, we discuss the results of our sudsy of a particle motion in the Relativistic Lagrangean framework. The conclusion was made that the relativistic proper mass is dependent on the gravitational and electromagnetic field. It is constant and equal to m_0 in free space, where the laws of Kinematics of Special Relativity Theory (SRT) hold; the constant proper mass m_0 and kinetic mass m_{kin} are relativistic components of the total mass $m_{tot} = \gamma m_0, \quad m_{kin} = (\gamma - 1)m_0$ where $\gamma = 1/\sqrt{1-\beta^2}$ is the Lorentz factor for a relative speed $\beta = u/c$ in a given inertial reference frame. As concerns Dynamics problems, the proper mass constancy in General Relativity Theory (GRT) and Relativistic Quantum Electrodynamic should be considered the linear approximation of a singularity-free unified (non-linear) field theory to be developed. In the next speculative part of the work the falsifiable concept of unified mediating (boson and spinor) field is discussed. We suggest the de Brogli wave interpretation in terms of excitation states of the field. In this concept, the real (transverse) photon should be treated as massles space-like boson, and the neutrino as a massless time-like fermion. Consequently, the notion of parity should be revised.

2 Physical principles of SRT Mechanics with gravitational forces

2.1 The relativistic mass-energy concept and the proper mass variation

In the Lagrangian formulation of Relativistic Mechanics of a single particle, the rate of 4-momentum change equals the Minkowski force. A variation of the proper mass follows from the corresponding SRT dynamical equations (using Synge's denotations [5]):

$$\frac{d}{ds}[m(s)\frac{dx_i}{ds}] = K_i(i = 1, 2, 3, 4) \tag{1}$$

They describe a particle motion on a world line $x_i(s), \vec{x} = \{x_1, x_2, x_3, ict\}$, with a 4-velocity dx_i/ds, where $K_i(s)$ is a Minkowski 4-force vector, and

s is a line arc-length. By definition of a time-like world line of a massive particle, we have the fifth equation:

$$\sum_i \frac{dx_i}{ds}\frac{dx_i}{ds} = -1 \tag{2}$$

that makes the problem definite with respect to five unknown functions: $x_i(s)$ and $m(s)$. The proper mass variation along the world line is explicitly seen from the next equation obtained from (1) and (2):

$$\frac{dm}{ds}\frac{dx_i}{ds} + m\frac{d^2x_i}{ds^2} = K_i \tag{3}$$

One may notice that in the common formalism of the Relativistic Mechanics the Minkowski force is orthogonal to the 4-momentum. However, when the proper mass variation is taken into account, the orthogonality condition does not take place:

$$\frac{dm}{ds} = -\sum_i K_i \frac{dx_i}{ds} \tag{4}$$

In this sense, the notion of the Minkowski force should be modified.

For the sake of convenience, one may consider the description of motion in 3-space ($\alpha = 1, 2, 3$) and time t ($i = 4$) rather than in spacetime ($i = 1, 2, 3, 4$) using the relation $ds = cdt/\gamma$ and formulas for relative ("ordinary") forces F_α:

$$F_\alpha = c^2 K_\alpha / \gamma \tag{5}$$

Now the equations of motion take the form:

$$\frac{d}{dt}(m\gamma u_\alpha) = F_\alpha \tag{6}$$

$$c^2\frac{d}{dt}(\gamma m) = \mathbf{F}\cdot\mathbf{u} + \frac{c^2}{\gamma}\frac{dm}{dt} \tag{7}$$

where $u_\alpha(t) = dx_\alpha/dt$ ($\alpha = 1, 2, 3$) is the 3-velocity, and the proper mass m is dependent on space and time coordinates in a given inertial reference frame. On the right-hand side of (7) the term $(\frac{c^2}{\gamma}\frac{dm}{dt})$ is recovered to account for the proper mass variation in a force field. The effect of the proper mass variation was noted in [5, 6] but was never paid attention in literature. For example, the fact that a particle speed cannot exceed the speed of light is often illustrated by the expression of motion of the particle driven by a constant inertial force $F_0 = Const$:

$$cp(t) = F_0 t,\ \beta(t) = F_0 t/\sqrt{m^2c^2 + F_0^2 t^2} \tag{8}$$

where the momentum $p(t)$ is proportional to the time elapsed. The mass in (8) is supposed to be a constant proper mass m_0, but this is not true. To check it, one has to consider a general problem on acceleration of the particle by a pulse of force with transients specified. It follows from (6) and (7) that the proper mass varies during transients. When the force reaches a plateau it becomes constant but different from m_0, the difference being a binding energy of a particle in the system "particle-accelerator". In the end of the pulse the proper mass acquires the initial value m_0 in a new state of free motion with kinetic mass-energy taken from the accelerator. *A dynamical change of the proper mass is a manifestation of a potential difference developed between the particle and the accelerator; consequently, the interaction should be characterized by the corresponding mass-energy current.* A general relativistic mass-energy formula following from (6) and (7) holds:

$$E(t)^2 = p(t)^2c^2 + m(t)^2c^4 \tag{9}$$

It describes the instantaneous state of a single particle in a force field and leads to (8) under a constant force condition. For a free motion, the equation (9) is reduced to the known SRT Kinematics formula

$$E^2 = p_0^2c^2 + m_0^2c^4 = Const \tag{10}$$

To consider the gravitational force problem in the relativistic framework, let us introduce a point-like particle of proper mass m_0 in a spherical symmetric gravitational field; the latter is characterized by a classical potential $\phi(r)$ due to a uniform sphere of mass $M \gg m_0$ and a radius R:

$$\phi(r) = -c^2(r_g/r), r \geq R \tag{11}$$

where $r_g = GM/c^2$ is a "gravitational radius" (G is the universal gravitational constant), r is a distance from the center of the sphere. So far, we assume that $R \geq r_g$. The potential (11) is defined per unit mass; the latter could be a rest mass of a test particle in the Newtonian Mechanics.

However, in the Relativistic Mechanics the proper mass of the particle becomes a function of the distance r:

$$m(r) = m_0 \exp(-r_g/r), r \geq R \tag{12}$$

where m_0 is a proper mass at infinity. In a weak field approximation ($r \gg R$) we have

$$m(r) \cong m_0(1 - r_g/r), \tag{13}$$

with a Newtonian limit $m(r) \rightarrow m_0$ at $r_g/r \rightarrow 0$. At $(r_g/r) \rightarrow \infty$ the proper mass tends to exhaust.

Once the proper mass variation is taken into account, a gravitational force takes a kinematical form:

$$F(r) = m_0 c^2 (r_g/r^2) \exp(-r_g/r) \tag{14}$$

One can find a relativistic generalization of the static potential function (11):

$$m_0 \phi(r) = \int_r^\infty F(r, m(r)) dr = -m_0 c^2 [1 - \exp(-r_g/r)], r \geq R \tag{15}$$

The expressions (14) and (15) have a point-like particle limit. In general, the proper mass of a test particle at a point $\mathbf{r}$ in 3-space uniquely characterizes a static gravitational field $\phi(\mathbf{r})$:

$$m(\mathbf{r})/m_0 = [1 + \frac{1}{c^2}\phi(\mathbf{r})] \tag{16}$$

The potential changes within the range $-c^2 \leq \phi(r) \leq 0$; therefore, it is limited by the factor c^2. This is a result of fundamental importance. It shows that *a singularity is absent in the relativistic form of gravitational potential.* One could find the same proper mass exhaustion effect in the case of the Coulomb attractive potential when the gravitational radius was replaced by "the annihilation radius" $r_a = k_0 Qq/m_0 c^2$ (k_0 is the electric constant at infinity). In the case of the electric repulsive force the annihilation radius should be taken negative; therefore, the proper mass increases with field strength ($m(r) \geq m_0$).

Let us consider Dynamics of a massive particle and a photon in a gravitational field. Conservative field properties become embedded in equations (6) and (7) if the total mass is taken constant and equal to that at infinity. Consequently, for a particle in free fall from rest at infinity) in the spherical symmetric gravitational field (11) we have:

$$m_{tot} = \gamma_r m(r) = m_0 \tag{17}$$

where $\gamma_r < 1$ characterizes a binding (dynamic) effect dependent on a radial position. Putting the expression for a gravitational force $F(r)dr = c^2 m(r) d(r_g/r)$ into equations (6) and (7), we have for $r \geq R > r_g$:

$$m_0^2 = m_0^2 \beta(r)^2 + m(r)^2 \tag{18}$$

$$m(r)/m_0 = 1/\gamma_r = (1 - r_g/r) = \sqrt{1 - \beta(r)^2} \tag{19}$$

$$\beta(r) = u(r)/c = \frac{1}{c}\frac{dr}{dt} = \sqrt{1 - (1 - r_g/r)^2} \tag{20}$$

The total energy conservation law is given in (18) as a relativistic relationship between the varying proper mass and the momentum. The expression (19) shows that a kinetic energy gain is equal to the corresponding potential energy change. Finally, the expression (20) describes a radial speed of a particle falling from rest at infinity. If the particle has an initial radial momentum $\gamma_0 \beta_0 m_0 c$ ($\gamma_0 > 1$), then, taking into account the total mass conservation $\gamma_0^2 m_0^2 = \gamma_0^2 m_0^2 \beta(r)^2 + m(r)^2$, we have $\gamma = \gamma_0 \gamma_r$, and the expression (20) is modified:

$$\beta(r) = \sqrt{1 - (1 - r_g/r)^2/\gamma_0^2} \tag{21}$$

The solution formally shows that the proper mass vanishes at $r = r_g$. Because a baryon charge of a single particle cannot be destroyed, we have to conclude that the above case cannot be physically realized: the result is valid at $r \geq R > r_g$. A particle carrying a non-zero proper mass in free fall can never reach the ultimate speed of light, though it constantly accelerates (the condition $\beta(r) < 1$, $d\beta/dr > 0$ always takes place).

To consider a radial motion of a photon in gravitational field one should take into account that the photon does not have the proper mass. It is seen from equations (6) and (7) that any force changes a momentum through the action on a total mass. Because the total mass is constant, the only way the photon can change the momentum is by changing the speed through a dependence on the gravitational potential $\phi(r)$. The following expression is consistent with SRT Mechanics:

$$\beta_{ph}(r) = c(r)/c_0 = 1 - r_g/r \tag{22}$$

Actually, this is the relative speed of wave propagation $c(r) = f\lambda(r)$ with a constant frequency $f = Const$. The speed is constant on an equipotential surface $r = r_0$; in this case, it may be termed a tangential, or arc speed. Henceforth the speed of light at infinity will be denoted c_0. In addition to (22), one can define the radial "coordinate" speed $c^*(r) = \beta^*(r)c_0$. It is measured by the differential time-of-flight method by an observer at infinity with the use of the so-called standard clock. If a unit length were found from circumference measurements, the radial scale would be determined by the field-dependent length unit proportional to the wavelength of the standard photon emitted from infinity $dr/d\lambda = (1 - r_g/r)$. Therefore:

$$\beta^*(r) = \beta(r)\frac{dr}{d\lambda} = (1 - r_g/r)^2 \tag{23}$$

As is seen, the photon while approaching the sphere slows down and tends to stop in a strong gravitational field at $r \to R \to r_g < R$. Our analysis of the phenomenon led us to the conclusion that the photon propagates in space of a gravitational field as in a refracting medium.

2.2 The metric determination by the criterion of agreement with experiments

In the relativistic world basic physical units become dependent on the gravitational field. How to measure them is the issue of theory foundations. Obviously, there are no absolute measuring units: what we have from observations are ratios with respect to the asymptotic values "at infinity". We consider the problem of metric determination in a broader sense than measurements of the space-time metric alone. The complete metric should include also units of 4-momentum vector components along with the speed of light, all of them are to be reanalyzed in a framework of the Lagrangian formulation of Relativistic Mechanics. (Further, we assume that an electric charge is field-independent). We see a solution of the problem in giving the proper mass a natural degree of freedom. In this new mass-energy concept, a test particle and a photon reveal new gravitational properties of fundamental importance. First of all, there is "an exhaustion" of the proper mass and, correspondingly, the potential energy in a strong field; this effect eliminates field singularities. Secondary, an interaction of the photon with the gravitational field is different from what is assumed in current theories. The photon behaves in a gravitational field as in an optically active (refractive) medium rather than like a particle in the field. It means that there is no coupling of the photon to the gravitational field. Consequently, a probing the field with the test particle and the photon results in a new field characterization and new metric relations of physical quantities.

We used the above results in conducting the metric analysis in order to determine basic physical units which could be transportable or reproducible throughout the space to make it possible to compare their values in a field and "at infinity". The standard (stable) test particle may be chosen to play the role of a quantum-mechanical oscillator when being used as a resonance emitter or a detector. The "standard atomic clock" will be the equivalent term for the standard particle. Then, characteristics of the electromagnetic wave emitted by the standard clock may be considered in choosing the standard units of length and time. From previous results, one can see that the frequency f_0 of the photon *emitted from infinity* by the standard clock at rest is a field-independent standard quantity; therefore, the corresponding period $\delta t_0 = T_0 = 1/f_0$ is a field-independent standard unit of time interval. We assert that the proper resonance frequency f_{res} of the standard atomic clock in the field is proportional to the proper mass at the radial point r', as in (19) for a spherical symmetric field. Thus, the frequency depends on a radial position of the atomic clock in the field, as next: $f_{res}(r') = f^0_{res}(1 - r_g/r') \propto m_0(1 - r_g/r')$. By definition, the inverse quantity is the field-dependent proper time interval $\delta\tau$ of the standard atomic clock at point r': $\delta\tau(r') = 1/f_{res}(r') = \delta\tau_0/(1 - r_g/r')$, where $\delta\tau_0$ is the proper time interval at infinity. It should be noted that so far we do not differentiate between the electromagnetic wave of light and the photon because the radial dependence of speed (22) is assumed to be the same for all frequencies (there is no dispersion). We admit that at ultra-high energy this assumption may be not valid.

Next, let us look for a field-independent unit of length. The instantaneous proper wavelength of the photon at any emission point r' can play this role. The wavelength is a ratio of the speed of wave propagation and the resonance frequency of an emitter $f_{res}(r')$; therefore, the standard *emission* wavelength λ_0 is constant and reproducible everywhere. We come to the important conclusion that *space-time mapping is possible in terms of field-independent units.* In general, the following formulas describe the field dependent proper time interval of the standard atomic clock and characteristics of the photon at point r, if emitted by the standard atomic clock at point r' (both the emitter and the detector being at rest in a sphere centered reference frame):

$$\delta\tau(r') = 1/f_{res}(r') = \delta\tau_0/(1 - r_g/r') \tag{24}$$

$$f_{ph}(r' \to r) = f_0(1 - r_g/r') \tag{25}$$

$$c_{ph}(r' \to r) = c_0(1 - r_g/r) \tag{26}$$

$$\lambda_{ph}(r' \to r) = \lambda_0 \frac{(1 - r_g/r)}{(1 - r_g/r')} \tag{27}$$

It is easy to incorporate in these formulas the Doppler effect caused by a relative motion of an emitter and a detector. The formula (24) describes the gravitational time dilation caused by a proper mass dependence on potential (19). From (24) and (25), it follows that there is a shift between the standard resonance frequency of the emission line at point r' and the absorption (detection) line at the point r (taking into account that the photon does not change the frequency in flight). As is seen from (26), the speed of the photon is a function of a radial position; it does not depend on the location of the emitter. From (27), the wavelength of the photon at the moment of emission at $r = r'$ is field independent and equals to λ_0 (transportable standard length unit). Notice that the proper time of atomic clock at some point at rest is measured as the oscillation period of the photon at the point of emission, and the photon carries this number during its flight over space of the gravitational field.

In the list of metric relations the speed of light plays a special role. The arc speed and the coordinate speed are different due to field medium anisotropy; they are the same in isotropic medium (a uniform field). As was noted, a field acts on a photon as a refractive medium with the index of refraction $n = 1/\gamma_r = (1 - r_g/r)$, which plays the role of the gravitational gauge factor. If so, there is no coupling of light to the gravitational field; therefore, the known argument that SRT is contradictory with observations of the bending of light in a vicinity of a gravitational center can be disregarded. The conclusion was made that the metric concept under discussion is consistent with the principles of Relativistic Mechanics, and it is falsifiable in the following sense: a) the metric relations (18-27), and their uniqueness can be experimentally tested and used for space-time mapping and mass-energy scaling in the *Minkowski space framework* ; b) integral experimental data related to gravitational properties of particles and photons can be consistently treated in Relativistic Mechanics. The known classical “weak-field” GRT tests (the gravitational red-shift, the bending of light, the time delay of light, the planetary perihelion precession) are fully explained, their predictions are in agreement with experimental data. c). Predictions of the new "strong-field" testable effects are made; one of them is the existence of superluminal particles in the gravitational field.

Our SRT-based metric analysis showed that our theoretical treatment of physical quantities is consistent with conservation properties of the gravitational field. Let us consider, for example, a metric relationship between the proper time interval $d\tau$ and the improper time interval dt of the particle in the gravitational field $ds = c_0 d\tau = c_0 dt/\gamma$ where ds is the arc length interval on the world line. The observer at infinity can verify it by measuring an instantaneous improper time interval and comparing it with the rate of his standard clock (similarly to imaginary experiments in SRT). The interpretation of the comparison procedure follows from our mass-energy concept: the proper time interval is the measure of the proper mass of the particle while the improper time interval is the Lorentz factor $\gamma = \sqrt{1-\beta^2}$ bigger, where the relative speed is meant with respect to the rest observer at infinity. Thus, the improper time is constant due to the total mass-energy conservation. A bound standard clock (attached to a shell or in orbital motion) has a smaller amount of total energy as compared to the similar clock in a hyperbolic motion. For example, the improper time of a particle in the shell of radius r is $dt = d\tau_0/\gamma_r$. For a free motion at infinity, the SRT relations are $m_{tot} = \gamma_0 m_0$ and $dt = \gamma_0 d\tau_0$; consequently, the metric form for a free floating state of the particle with $\gamma_0 > 1$ is

$$ds(r) = c_0 d\tau(r) = c_0 dt(r)/\gamma \tag{28}$$

with the kinematical Lorentz factor $\gamma = 1/\sqrt{1-\beta(r)^2} = \gamma_0\gamma_r$, as in (21), and the dynamical factor $\gamma_r = 1/(1 - r_g/r)$. Therefore, relations between the field-dependent metric form ds, the proper time of atomic clocks rested at infinity $d\tau_0$ and in a free-floating state $d\tau(r)$ are:

$$ds(r) = c_0 d\tau_0/\gamma_r \tag{29}$$

$$d\tau(r) = d\tau_0/\gamma_r \tag{30}$$

In the particular case of the particle in free fall from rest at infinity, we have $\gamma_0 = 1$, $\gamma_r m(r) = m_0$, and $dt = d\tau_0$; it describes conservation properties of gravitational field with the following identities characterizing a rotational symmetry in the 4-coordinate and 4-momentum space:

$$p^2/m_0^2c_0^2 + m^2/m_0^2 = 1, m/m_0 = 1/\gamma_r \tag{31}$$

$$dr^2/d\tau_0^2c_0^2 + d\tau^2/d\tau_0^2 = 1, d\tau/d\tau_0 = 1/\gamma_r = \sqrt{1-\beta^2} \tag{32}$$

The corresponding metric relation is $ds^2 = c_0^2 d\tau_0^2 - dr^2$; the angle and the rate of the Minkowski space rotation can be found. Having a solution to equations of motion (1) for some specific problem, one can find scalar products of 4-vectors $s^2 = \mathbf{x}\cdot\mathbf{x}$, $p^2 = \mathbf{p}\cdot\mathbf{p}$ and construct the antisymmetrical tensor $M_{ik} = x_i p_k - x_k p_i$ to check the angular momentum conservation as well. *The "gamma" transformation $q(r) \to q_0/\gamma_r$) of basic metric units in Minkowski space reflects the rotational symmetry being identical in the 4-coordinate and 4-momentum space.* Obviously, this is the reflection of conservation field properties.

One may compare our SRT space-time metric of the static spherical symmetric field

$$ds^2 = c_0^2 d\tau^2 = c_0^2 dt^2 - dr^2 \tag{33}$$

with the corresponding GRT (Schwarzschild) metric, in the polar coordinate system, for simplicity:

$$ds^2 = c_0^2 dt^2 (1 - 2r_g/r)^2 - dr^2/(1 - 2r_g/r)^2 - r^2 d\phi^2 \tag{34}$$

In the weak-field approximations, which is convenient for the purpose of our comparison, it is equivalent to the form

$$ds^2 = c_0^2 (dt/\gamma_r)^2 - (\gamma_r dr)^2 - r^2 d\phi^2 \tag{35}$$

where $\gamma_r = 1/(1 - r_g/r)$. Then, the Schwarzschild solution reflects GRT metric relations, as follows:

$$dr' = \gamma_r r, \quad dt' = dt/\gamma_r, \quad c' = c_0, \quad m' = m_0 \tag{36}$$

It is apparently consistent with gravitational experimental data, which have been obtained essentially from "weak-field" experiments.

One can deduce the coordinate speed and the arc speed from (34) by putting the "light-cone condition" $ds^2 = 0$; the expressions will appear the same as we have in (23) and (22), but they should be regarded as "metric induced" quantities. In the GRT treatment of experiments the speed of light c_0 and the proper mass of elementary particle are considered field-independent physical constants. This assumption is a part of the GRT metric methodology of operations with "wristwatches" and "rigid measuring rods". It is not possible to establish a relationship of those operations with physical processes of probing a field with test particles, and the role of the photon in a metric determination is not clear. Recall that our metric of basic physical quantities is

$$dr' = dr, \quad dt' = dt, \quad c' = c_0/\gamma_r, \quad m' = m/\gamma_r \tag{37}$$

which has uniquely resulted from the analysis of a photon and particle motion in the gravitational field and the methodology of transportable and reproducible standard units. While the GRT metric contains singularities under strong-field conditions, our metric is free of singularities in the whole range of energy.

3 The hypothesis of boson and spinor mediating fields, and the de Broglie waves

3.1 The de Broglie wave in the massless boson field concept

Next, the concept of the 4-vector field mediating the gravitational and electromagnetic interactions is described. At this point, we do not suggest field equations; instead, we invite readers to discuss speculative issues of the new idea of field unification on the basis of the relativistic generalization of the classical $1/r$-potential. The field is expected to be non-linear; therefore, conventional field formalism needs to be changed. One shall see that understanding of the relativistic nature of the de Broglie wave phenomenon could be an important step towards the development of the unified divergence-free theory.

We found that both gravitational and electromagnetic field, though having different structure, are related to the common source that is, the proper mass; clearly, this is the clue for the unified theory concept. *Our general idea of the field unification is to add the gravitational (mass) source and mass-energy (neutral) current to corresponding parts of the electromagnetic field in the covariant form.* Consequently, field strength parameters will be automatically coupled; they will play the role of dynamical "feedback" variables. Obviously, the variable proper mass makes the unified field theory non-linear. One can try to realize this concept within the Lagrangian formulation by applying the variational principle to the extremal proper mass problem. It is expected that equations of motion will consistently describe the total energy-momentum tensor of the particle system and yield an electromagnetic field and a massless mediating boson field. However, it is not immediately clear how to formulate the problem of multiple interacting sources of unified field. In the linear field concept with the proper mass being constant the superposition principle holds, and the $1/r$-potentials are usually meant retarded. In our field concept a point-like source and a point-like test particle form a system of two interacting particles with the radius of interaction (field strength parameter) determined by properties of both particles. It seems that retarded and advanced potentials are needed to account for both outgoing and ingoing interfering waves. It would be reasonable to consider a massless boson mediating field in the Klein-Gordon framework with the variable proper mass. Spin properties of sources are not specified there. We assume that force transmitting virtual (pure imaginary) photons are of two types: longitudinal and scalar (time-like) photons; the latter have to contribute to the mediating scalar gravitational interaction. Real (transverse) photons are not mediators; they have the status of free particles which can exist independent of sources and be utilized in cross-section measurements. This is in agreement with the Gupta-Bleuler formalism [7, 8] distinguishing between observable (Hermitian) and mediating (anti-Hermitian) particles. Thus, we want to interpret it in a "strong" form: all interactions are due solely to anti-Hermitian photons. They are physical vacuum excitation states resulting from massive particle interactions. In this scheme gravitational properties of real photons should be explained in terms of their interaction with the boson field. This concept allows us to gain a new insight into the de Broglie wave nature.

The de Broglie waves are commonly known from observations of free moving particles, first of all, in interference experiments. Let us consider the dynamics of the wave origination. In the familiar example of an attractive interaction, the following equation describes the dynamical energy conservation balance:

$$p^2/c_0^2 + m^2 = m_0^2 \tag{38}$$

with $m/m_0 = (1 - x_s/x) \leq 1$ where x_s is a field strength parameter. The de Broglie wavelength λ_{dB} due to the momentum transfer may be derived from the Einstein's and de Broglie's quantum-mechanical expressions $p = h/\lambda_{dB}$ and $m_0 = hf_0/c_0^2$ together with our formula for the particle momentum $p = m_0 c_0 \beta$. Then, the equation (38) in terms of frequencies is equivalent to the following:

$$f_{dB}^2 + f^2 = f_0^2 \tag{39}$$

$$(\lambda_0/\lambda_{dB})^2 + (m/m_0)^2 = 1 \tag{40}$$

The field-dependent frequency $f(t)$ is related to the proper mass of the atomic clock. The corresponding proper wavelength of the atomic clock oscillation is $\lambda(t) = c_0/f(t) = h/m(t)c_0$, at initial moment being equal to $\lambda_0 = h/m_0c_0$. According to our metric, it increases during a particle acceleration. Note that the de Broglie wavelength is determined by the spatial part of the 4-wave vector; the proper mass component is a time-like quantity, which vanishes in the annihilation process. Thus, the de Broglie wave characteristics are momentum (space-like) quantities. Unlike the proper wavelength, the de Brogli wavelength decreases during the particle acceleration in free fall. The particle wave should have the form $a(x,t) \propto \cos(ft - kx))$, where $f(t) = c_0^2 m(t)/h$, $k(x) = c_0 m_0 \beta(x)/h$, $\beta(x) = \sqrt{1-(m/m_0)^2}$, $m/m_0 = (1 - x_s/x)$, $x = x(t)$.

The connection is seen between conservative field symmetries previously discussed and the de Broglie waves. Characteristics of the waves are present in relativistic metric relations, which we derived from completely different principles. The whole picture can be visualized. Imagine a particle at rest producing a static spherical symmetric field. The particle has one degree of freedom (the scalar mode) what may be thought of as the sphere pulsation. The pulsating sphere in motion exhibits known relativistic effects of length contraction and time dilation giving rise to the vector mode of oscillation that is, the de Broglie wave phenomenon. The group speed is the particle speed while the corresponding phase speed exceeds the ultimate speed of light. In traditional interference experiments the wave becomes polarized in a plane after coming through a single slit. An experimentalist can rotate the plane of polarization of electrons, for example, by creating an accelerating field between the slit and a screen. The plane rotation is the predicted relativistic effect which could be verified, in principle.

It is seen now that the "probability wave" concept in the non-relativistic quantum-mechanical theory should be considered an approximation, which could be somehow justified under weak-field conditions (a proper mass constancy). In our relativistic picture, the source of the de Broglie waves is the moving particle in a fixed reference frame (the cp term in the equation $cp = hf_{dB}$). Thus, a particle interference pattern is frame dependent. At the same time, the de Broglie waves are associated with an excitation of physical vacuum states (virtual photons) in the process of transformation of the proper mass into kinetic one. The excitation process propagates in space with the ultimate speed of light and should be treated in terms of coherent ingoing and outgoing waves of the boson field. From this point of view, the wave nature of particles (the de Broglie waves, tunneling effects and entangled collective states) may be fully understood; however, the concept of "physical vacuum" and the term "at infinity"need to be clarified. Intuitively, one may think of a spherical shell of universe matter as the source of "physical vacuum field" with a finite energy density. Then, the physical vacuum in the shell is a background field for local fields in a cosmological potential well. In this sense, to reach "infinity" means to get rid of all local fields. For an atomic electron it could be a fraction of millimeter away. A single free particle moving in the space of a constant residual potential is in equilibrium with the physical vacuum (with the universe): there is no net mass-energy, or a virtual photon, current between the particle and the universe. This is a local particle-particle interaction, which breaks this equilibrium and results in the net current between interacting particles and the universe. The direction of current is determined by the field gradient depending on the type of interaction. The process is traditionally described in the quantum-mechanical concept of the photon exchange mechanism to be revisited in the future non-linear theory. We emphasize here the importance of relativistic mass-energy concept (a proper mass variability) with cosmological connections as well as a possible universal role the 4-vector boson field (virtual photons) in a unified field theory. In fact, we assume that virtual photons mediating gravitational and electromagnetic forces are revealed in the form of the de Broglie waves, which should be subject to further theoretical and experimental study.

3.2 On symmetries in the spinor field concept

A consideration of particle spin properties will require the next-level theory, presumably, in the spinor (Dirac) framework. Again, the concept of variable proper mass should be incorporated in the theory. Then, the boson field could be treated as a composite field. A spin is both quantum-mechanical and relativistic quantity and, as such, seems to be poorly understood. A massive fermion spin, which appears in a helicity operator of a massive particle $(\sigma \cdot \mathbf{p})$, is not Lorentz invariant; but it is invariant in the case of a massless Dirac neutrino. This conundrum should be esolved. In classical terms, one can associate the spin with the particle rotation. But what can give a neutrino a rotational mode when there is no neither proper mass nor magnetic moment? We think that our treatment of the de Broglie waves allows us to gain a new insight into the nature of spin. As was shown, a massive particle is a relativistic object characterized by the 4-wave vector having a spatial (the de Broglie wave) and a time-like (the scalar wave) parts. The corresponding source of virtual photons is the momentum of a massive particle. In a process of proper-to-kinetic mass transformation, real (transverse) photons can emerge as the result of the proper mass annihilation or electromagnetic transitions between resonance states in a bound systems (for example, in atoms) formed by attractive forces. Thus, the photon having no proper mass may be considered a kinetic mass-energy quantum, that is the quantum of a vector field, or electromagnetic energy carrier. In this sense, the photon is a pure space-like real object. Could a pure time-like real "photon" exist as a proper mass quantum? We think that this question relates to the fundamental issues of space-time-matter symmetries. These issues are further discussed in the form of brief speculative questions-answers.

Could the mediating boson field be considered in terms of composed virtual neutrino pair states?

We suggest considering virtual photons in the Dirac framework to be field states composed of virtual neutrino pairs; they play the role of "force transmitters" (but not energy carriers) in gravitational and electromagnetic interactions as well as in "weak" reactions. Bosonic modes of the field in terms of virtual neutrino pair $\tilde{\nu}, \nu$ could be presented in symbolic (conjugation) form $(\nu\nu)$, $(\tilde{\nu}\tilde{\nu})$, $(\nu\tilde{\nu})$. This would provide a natural connection between the Klein-Gordon and Dirac framework. Moreover, one can try to reveal "glueing" properties of the virtual photons when considering the intimate relationship between particles.

Is the neutrino a time-like massless real fermion? Does the real bosonic electron exist?

We admit that in a future theory a massive particle will be considered a physical vacuum resonance in a cosmological field; a resonance state could be treated as "a droplet" of the field Bose-condensate with the "proper mass" proportional to the number of condensed virtual photons. This hypothetical picture provides a future theory with opportunities of new physical ideas about matter structure. For example, an elementary fermion, like an electron or a proton, could be a stable ground-state formation finished with a valence proper mass fermionic quantum. Therefore, one may think of the fermion particle being "entangled" through the boson field with universe matter. Then the neutrino seems to be a natural candidate for the proper mass quantum. Let us assume that neutrinos are produced in interactions due to the so-called degenerate-pressure force, for example, between the proton and the electron at distances smaller then the Bohr radius. In accordance with our mass-energy concept, the electron proper mass under such conditions becomes greater than that at infinity. When it reaches the resonance state about 106 Mev, the muon is created, which interacts with the proton to produce the neutron. The muon should be considered an exited electron being subject to decay with neutrino-antineutrino emission. When the muon interacts with the proton, the electron undergoes the stage of coupling to neutrino. If this picture is true, the electron-neutrino bound state is real that is, the electron can exist in a free baryon state (as a real bosonic electron), which could be detected. One cannot exclude that hypothetical bosonic electron plays the important role in superconductivity. In the inverse reaction of the neutron decay the bosonic electron decays with the neutrino flying away. Thus, the neutrino could indeed be the proper mass quantum able to form pairs of coupled virtual photons or to couple to any fermionic particle. Thus, we hypothesize that the bosonic proton and the bosonic electron exist as real particles (most likely with short lifetime).

In the above picture, there is a principle difference between the real photon and the neutrino. The photon carries the momentum but does not have an angular momentum: in a circular polarization mode it reveals a rotation of a plane polarization due to the phase shift with no rotational kinetic energy. Unlike the photon, the neutrino being the proper mass-energy quantum carries inner angular momentum with no linear momentum ("screw-type particle"). Such a particle has one degree of freedom. It should be called a pure time-like particle. One may expect that the neutrino does not produce the de Brogli waves, neither it does the Doppler shift. The neutrino should behave in the gravitational field as the proper mass quantum: the frequency icreases with the field strength while the speed remains equal to the ultimate speed of light. This is in agreement with small cross-sections of neutrino interaction with matter. The "unusual" predicted neutrino properties should be subject to further theoretical and experimental investigation.

Is there a violation of P, CP or T symmetry?

Given the neutrino being the proper mass quantum, considerations of the parity issue gives us the thought that there is no physical reason for the mirror symmetry in particle physics; "the neutrino" and "the antineutrino" automatically have opposite handedness by virtue of the angular momentum conservation; therefore, the question of existence of both right-handed and left-handed neutrinos (or the world being left-right symmetric) becomes ill-posed. The parity is a concept of non-relativistic ("probability wave") quantum mechanics. We assert that the CPT theorem should be replaced by a relativistic invariance concept of the 4-coordinate reverse symmetry with a properly defined conjugation operator in a boson and spinor field. In other words, the concept of antimatter needs to be revised.

Do neutrino flavors exist?

Reactions with neutrinos are called "weak interactions" in the so-called electroweak model of spontaneously broken symmetry [9]. The model is a part of the Standard Particle Model (SM), which introduces special neutrino properties called "neutrino flavors" emphasizing a physical difference of neutrinos in electron and muon reactions. In our view, both the model of "electroweak unification" (by introducing massive mediating bosons) and the neutrino flavor concept have no physical grounds. In the above concept of the bosonic electron, typical neutrino reactions should be expressed in the following form revealing the mediating role of massless boson field. For a certain reason, the electron is considered the antiparticle, then the conventional "antineutrino" becomes "the neutrino".

$$\tilde{\mu} \to \tilde{e}\nu + \nu \to \tilde{\nu} + \nu + \tilde{\nu}. \tag{41}$$

$$\nu + p = \nu n e \tilde{\nu} \to n + \mu \to n + e\tilde{\nu} + \nu \to n + e + \nu + \tilde{\nu} \tag{42}$$

$$\tilde{\nu} + n = \nu p \tilde{e} \tilde{\nu} \to p + \tilde{\mu} \to p + \tilde{e}\nu + \tilde{\nu} \to p + \tilde{e}\nu + \tilde{\nu} \to p + \tilde{e} + \nu + \tilde{\nu} \tag{43}$$

$$n \to p + \tilde{e}\nu \to p + \tilde{e} + \nu \tag{44}$$

According to the Standard Model (SM), the above reactions are different for incident so-called muon neutrinos (typically, from a muon decay) and so-called electron neutrinos (typically, from fission and fusion reactions). The SM predicted muon-type and electron-type neutrino reactions are

$$\nu_\mu + p \to n + \mu, \tilde{\nu}_\mu + n \to p + \tilde{\mu} \tag{45}$$

$$\nu_e + p \to n + e, \tilde{\nu}_e + n \to p + \tilde{e} \tag{46}$$

The muon-type reaction was confirmed by the experiment conducted in 1961 – 1962 at the Brookhaven AGS Facility with a high time-resolution technique [10]. However, a similar experiment with "electron neutrinos" required to check the prediction of electron-type reaction (46) was never performed. In our concept, neutrinos in all above reactions are the same massless Dirac neutrinos, which are physically indistinguishable.

4 Conclusion

The de Broglie wave is essentially relativistic phenomenon closely related to the problems of mass origin and self-energy divergence. In our SRT-based approach, the problem of $1/r$ field singularities is recognized as the metric problem of dependence of basic (space-time and proper mass) units and the speed of light on the gravitational potential. The metric problem was analyzed in the Lagrangean formulation of Relativistic Mechanics. The criteria of our metric determination were the consistency with the covariant form of equations of motion in a conservative force field and the agreement with experimental data. It was found that the proper mass and the speed of light are field dependent; they uniquely characterize the gravitational field. Consequently, the new metric provides a unique mapping of the field with the use of a light signal and a test particle. Experimental data and predictions (de Brolie wave properties included) are consistently treated in terms of Relativistic Mechanics. Among the important results are, as follows:

- There is no reason for the exclusion of gravitational forces from the theory of Relativistic Mechanics. Gravitational Physics different from General Relativity Theory follows from the consistently formulated Relativistic Mechanics. The corresponding SRT-based approach to the gravitational field problem is suggested in agreement with observations. One of the predictions is an existence of superluminal particles in a gravitational field; the prediction can be experimentally verified.

- A field due to the gravitational and electric sources is shown to be inherently free of singularities; therefore, a renormalization procedure is not needed. The idea of the unified field concept based on the massless boson and spinor fields is suggested. In the concept, the neutrino does not have "flavors". It plays the fundamental role of a proper mass quantum having new physical properties. In particular, an inability of the neutrino to produce the de Broglie waves is predicted.

- The de Broglie waves are characterized by the 4-wave vector (spatial and time) components and should be treated in terms of excitation states of the mediating boson field. In this concept, the parity notion is the product of non-relativistic quantum mechanics. Consequently, the parity violation problem becomes ill-posed; the physical treatment of the discrete space-time symmetries should be revised in the future unified field theory.

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