Tunneling of the potential barrier and particle's size in the Extended SpaceModel

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We consider a generalization of the special theory of relativity (STR) at a 5-dimensional space, and more specifically at (1 + 4) -dimensional space with (+ - - - -) metric. In the Extended space model (ESM), in contrast to the Special theory of relativity a rest mass m of the particle, is not constant, but can change its value as a result of external influences. We consider a 5-vector potential, which is a generalization of the usual 4-vector potential of the electromagnetic field. It creates tension, which a form 10-component tensor of the 2nd rank. The components of this tensor include the electric and magnetic fields, as well as 4 more additional fields. Using the rotation in this space, one can transform field strengths in each other. It gives us an opportunity vanish the electric and magnetic fields, and concentrate all energy in four additional components. It permits us to propose in the frame of the ESM a new mechanism to tunnel the Coulomb barrier by photons. The other effect that exists in the ESM is the appearance of some spatial scales. The scales are different for different types of particles and interactions. We connect these scales with appearance of particle size.

Keywords: Special theory of relativity, 5-dimensional Extended Space Model, interval, variable photon mass, coulomb barrier, size of particle.

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Introduction

In recent years various theoretical models that allow one to offer new mechanisms to tunnel the Coulomb barrier by charged particles are actively discussed in scientific literature. In particular such mechanisms were proposed in [1-3]. In this paper, we consider another possible mechanism to tunnel the Coulomb barrier. It is formulated in the frame of the our 5-dimensional (1 + 4)-dimensional Extended Space Model (ESM) [4-7]. The ESM is a generalization of the

Special theory of relativity (STR) to a 5-dimensional space with metric (+ - - - -).

In the contrary to STR in the ESM a rest mass m of a particle is not a constant and can change its value as a result of external influences. A quantity that conjugates to mass is an action. The action has sense the 5-th coordinate in the ESM. The (1+3)-dimensional Minkowski space is a subspace of the Extended space. In MCI is considered 5-vector potential, which is a generalization of the usual 4-vector potential of the electromagnetic field. He creates tension, which form 10-component tensor of the 2nd rank. Among the components of this tensor includes the electric and magnetic fields, as well as 4 more new additional fields. One of them is a scalar with respect to the Lorentz transformations in Minkowski space, and the other three - vector components.

Electromagnetic field structure in the Extended Space Model.

Using the rotations in the Extended Space Model, one can transform field tensions in each other. It gives an opportunity nullify the tension of electric and magnetic fields, and concentrate the energy in four additional components. This effect gives us an opportunity to offer in the framework of ESM, a new mechanism to tunnel the Coulomb barrier by photon. In the ESM a free electromagnetic wave falling in an external field transforms to a new state in which the electromagnetic components go into additional components. These components are not arise in the ordinary field theory, and they don't interact with Coulomb barrier.

In the ESM the transformations, which are additional to Lorentz transformations, lead to change the particles rest mass, in particular to emergence of photon mass. This mass can be either positive or negative. The change of mass causes a change of the laws of interaction of particles with the electromagnetic field. This can lead to effects that do not fit the traditional picture of the interaction of electromagnetic radiation with matter.

Another effect that arises naturally in the EAM is the appearance of some spatial scales. They are different for different types of particles and interactions. The value of these scales can be related to magnitude of changes of particles mass. These scales may be associated with a particle size.

In particular in the ESM the infinite plane waves, which are compared to particles in the usual field theory, are deformed and take the finite size under the influence of external influences.

In the previous papers [4-7] we proposed a generalization of the Special theory of relativity (STR) at a 5-dimensional extended space with metric (+, -, -, -, -). We construct a model that combines electromagnetic and gravitational interactions. This model is formulated in the extended space in which the fifth coordinate s is added to the ordinary spatial coordinates (x, y, z) and time t.

From geometric point of view s is an interval in Minkowski space, but physically we associate it with a refractive index n.

The mass of the particle changes when it moves along the axis. The change of a mass leads to a change in the gravitational field created by it.

In particular, zero mass particles (photons) when entering from the empty space with n = 1 into a medium with n> 1, acquire nonzero mass and become a source of gravitational field. The system united of equations that describe such processes was proposed in [4,7].

In this space we constructed mechanic equations for a massive point particle [4,7] and electrodynamical equations [5,6]. We found as well Lienard-Wiechert potentials and analyzed the properties of their corresponding solutions of the extended system of the Maxwell's equations.

We considered also the gravitational effects in the extended space, such as the escape velocity, the red shift and the deflection of light [6]. It is shown that the formulas are obtained in the general theory of relativity to calculate the magnitude of these effects; one can get a completely different way in the Model of extended space. In order to do this, it was assumed that the gravitational field in the space creates a certain refractive index n, which depends on the strength of this field. This refractive index n defines the rule of movement of photons and massive particles in this space. In the frame of the ESM one can find all gravitational effects with the help of rotations in the Extended space.

Here we summarize the main results obtained in previous works.

It is proposed a generalization of STR, which takes into account the processes in which the particle mass m would be variable. Under the particle mass m, following the recommendations of the review [11], we understand its rest mass, which is a Lorentz scalar. To do this, first of all, we construct the expansion of (1+3) -dimensional Minkowski space by (1+4) -dimensional space which we call the extended space.

As a fifth additional coordinate we use the interval S, which is already exists in the Minkowski space.

$$S^2 = \left(ct\right)^2 - x^2 - y^2 - z^2 \tag{1}$$

This value is conserved under the ordinary Lorentz transformations in Minkowski space but changes under the rotations in the Extended space. The Minkowski space is a cone in the Extended space. In this space, the quantity

$$s^2 - (ct)^2 - x^2 - y^2 - z^2 = const \tag{2}$$

is conserved.

It is known that the energy, pulse and mass of a free particle are connected by a relation [11].

$$E^2 - c^2 p_X^2 - c^2 p_Y^2 - c^2 p_Z^2 - m^2 c^4 = 0 \tag{3}$$

It is an analogue of (1) in the space conjugate to the space $G'(E;\vec{P},M)$. The mass m is the quantity that conjugate to the interval S.

The Lorentz transformations change the particle's energy E and its pulse, but conserve the mass m. The transformations in the Extended space, additional to Lorentz transformations, change the mass m of the particle, conserving in general case only the form (4).

$$E^2 - c^2 p_X^2 - c^2 p_Y^2 - c^2 p_Z^2 - m^2 c^4 = const \tag{4}$$

In Minkowski space $M(E;\vec{P})$ the pulse-energy 4-vector

$$\tilde{p} = \left(\frac{E}{c}, p_x, p_y, p_z \right)$$

corresponds to a free particle. The components of this vector are connected by the relation (3).

In Minkowski space, all particles are divided into two types: massive, which are characterized by a mass m, and massless (photons), which are characterized by a frequency. In ESM the rest massiv solid particles are associated with 5-energy-momentum-mass vector-weight: $\bar{p}_m = (mc, \vec{0}, mc)$.

A photon moving in empty space with velocity c in the direction $\vec{k}$ is characterized by a 5-energy-momentum-mass vector $\bar{p}_{\hbar\omega} = \left(\frac{\hbar\omega}{c}; \frac{\hbar\omega}{c} \vec{k}, 0 \right)$.

One can see that both these vectors are isotropic. Therefore in the ESM isotropic vectors in $G'(E, \vec{P}, M)$ correspond both to massive and massless particles.

The rotations in the space $G'(T, \vec{X}, S)$, additional to the Lorentz transformations, mix coordinates corresponding space and time with the a new coordinate S. In the dual space such rotations transferred energy and momentum into mass and vice versa [4,5].

Let's consider now the electrodynamics in Extended space.

In ordinary electrodynamics the electromagnetic field is generated by 4- current vector. One can obtained this vector from the 4- energy-momentum vector of a charged particle by dividing it by the rest mass m of the particle and multiplying by the charge density.

It is a correct procedure because in the Special theory of relativity both the rest mass of the particle and its charge are considered to be scalars. This current is the source of the electromagnetic field, which is described by 4-vector potential. And each component can be considered as a current source of the corresponding component of the vector potential.

In ESM model a particle is associated with 5-energy-momentum-mass vector. Its fifth component expressed in terms of the rest mass of a particle and for this reason it can be associated with gravitational field. We want to get a current, which is a source of electromagnetic and gravitational fields. For this aim we multiply the 5-vector at the charge density. It's still a correct procedure because in the ESM a charge is a scalar. But the mass in the extended space is not a scalar.

In the traditional formulation of the electromagnetism the current is a 4-vector in Minkowski space. It is necessary to transform the 4-dimensional current vector into 5-dimensional vector. As in the case of energy-momentum vector, we demand that the vector was isotropic. Therefore, we obtain [5,7].

$$\overline{\rho} = \left(\rho, \vec{j}, j_s\right) = \left(\frac{\rho_0 c}{\sqrt{1-\beta^2}}, \frac{\rho \vec{v}}{\sqrt{1-\beta^2}}, \rho_0, c\right), \ \beta^2 = \frac{v^2}{c^2} \tag{5}$$

Here ρ_0(t, x, y, z) - is the electric charge density at the point (t, x, y, z) in the laboratory coordinate system. It is invariant under Lorentz transformations and is an analogue of the rest mass of the particle.

The value $\vec{v} = v_x\left(t,x,y,z\right),\ v_y\left(t,x,y,z\right),\ v_z\left(t,x,y,z\right)$ - is the local velocity of the charge density.

In the Extended space model the first four components of the 5-current vector (5) are a source of electromagnetic field, and the fifth component - is a source of gravitational field. More precisely, this separation takes place in the case when there are no processes that change the rest mass of the particles, if such processes occur, the two fields are combined into a single electromagnetic-gravitational field.

Additional transformations which are exist in Expanded space, change a value of ρ_0 in the same way as they change the rest mass m.

In order to describe the phenomena both in terms of point particles and in terms of fields and waves also, we propose the following formalism.

In the Extended space of the current (5) provides a field that describes by the 5-vector potential

$$\left(\varphi,,\overrightarrow{A},A_4\right)=\left(A_t,A_X,A_Y,A_Z,A_S\right) \tag{6}$$

The potential (6) and the current (5) are related by equations [5,7]

$$\Diamond A_t=-4\pi\rho \tag{7}$$

$$\Diamond\vec{A}=\frac{-4\pi}{c}\vec{j} \tag{8}$$

$$\Diamond A_S=\frac{-4\pi}{c}j_S \tag{9}$$

Here

$$\Diamond=\frac{\partial^2}{\partial s^2}+\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2}-\frac{1}{c^2}\frac{\partial^2}{\partial t^2} \tag{10}$$

The field that corresponds to potential (6), contains in addition to the conventional electric and magnetic components some additional components. It corresponds to the fact that in the process of interaction the mass of the particle can vary. With the help of potential (6) one can build the tensions tensor of the field

$$F_{ik}=\frac{\partial A_i}{\partial x_r}-\frac{\partial A_k}{\partial x_i};i,k=0,1,2,3,4.$$

$$\left\|\mathrm{F}_{\mathrm{ik}}\right\|=\begin{pmatrix} 0 & -E_X & -E_Y & -E_Z & -Q \\ E_X & 0 & -H_Z & H_Y & -G_X \\ E_Y & H_Z & 0 & H_X & -G_Y \\ E_Z & -H_Y & H_X & 0 & -G_Z \\ Q & G_X & G_X & G_X & 0 \end{pmatrix} \tag{11}$$

Here the new fields Q and $\vec{G}$ are appeared in the tensions tensor (11)

$$Q = F_{40} = \frac{\partial A_4}{\partial x_0} - \frac{\partial A_0}{\partial x_4} = \frac{\partial A_S}{c\partial t} - \frac{\partial \varphi}{\partial s} \tag{12}$$

$$G_x = F_{41} = \frac{\partial A_4}{\partial x_1} - \frac{\partial A_1}{\partial x_4} = \frac{\partial A_S}{\partial x} - \frac{\partial Ax}{\partial s} \tag{13}$$

$$G_Y = F_{42} = \frac{\partial A_4}{\partial x_2} - \frac{\partial A_2}{\partial x_4} = \frac{\partial A_S}{\partial y} - \frac{\partial A_Y}{\partial s}$$

$$G_Z = F_{43} = \frac{\partial A_4}{\partial x_3} - \frac{\partial A_3}{\partial x_4} = \frac{\partial A_S}{\partial z} - \frac{\partial A_z}{\partial s}$$

The tension tensor (11) contains, in addition to the components that are analogous to conventional electric and magnetic fields, the additional components that describe the gravitational field. More precisely, in the case when components of 5-current vector (5) depend on the coordinate s, all components of the tensor (11) describe a single electro-gravitational field. If the current does not depend on the coordinate s, then the system of equations (7- 9) splits into two: at the system of Maxwell's equations and the Laplace equation for the scalar gravitational field.

Thus, according to ESM, in empty space gravitational and electromagnetic fields are exist separately, but in the area where external forces affect at the particles and fields, they are combined into one single field.

The expression for the forces acting on a particle of charge e and mass m, by the field (11) was found.

We suppose that in the reference frame K ', which moves in the Extended space $\mathrm{G}(\mathrm{T};\vec{\mathrm{X}},\mathrm{S})$ together with a charged particle, the force is given by the 4-vector $\mathrm{F}' = (\mathrm{e}\vec{\mathrm{E}}', \mathrm{eQ}')$. In such frame of reference the equations of motion read

$$\frac{d\vec{p}}{dt} = e\vec{E}', \frac{dp_s}{dt} = eQ'. \tag{14}$$

In the transition to another reference frame by a rotation in the space $G(T;\vec{X};S)$ the field (11) is transformed by the rules established in [5,6].

Let's consider some examples of such transformations.

The parameters $(v, v_S, \vec{u})$ define the transition from one coordinate system to another. 1) The $(T\vec{X})$ - transformation is characterized by velocity $\vec{v}$. Under these rotations the field (11) is transformed as follows:

$$\vec{E}' = \vec{E} + \frac{1}{c}(v, \overrightarrow{H}), \vec{G}' = \vec{G} + \frac{v_s}{c}\vec{E}, \vec{H}' = \vec{H}, Q' = Q. \tag{15}$$

2) The (TS)-transformation is characterized by velocity v_S along the coordinate axis S. Under this rotation the field (11) is transformed as follows:

$$\vec{E}' = \vec{E} + \frac{v_s}{c}\vec{G}, \vec{G}' = \vec{G} + \frac{v_s}{c}\vec{E}, \vec{H}' = \vec{H}, Q' = Q \tag{16}$$

3) The $(S\vec{X})$ - transformations are characterized by a vector parameter $\vec{u}$.

It characterizes the change in the refractive index n when moving along the direction $\vec{u}$. Under these rotations the field (11) is transformed as follows:

$$\vec{E}' = \vec{E} - \vec{u}Q, \vec{G}' = \vec{G} + \left[\vec{u}, \vec{G}\right], Q' = Q + \frac{1}{c}\left(\vec{u}, \vec{E}\right). \tag{17}$$

By applying this transformation to the system (14) one can find the Lorentz force acting on the moving particle. For the selected sequence of transformations (TS) + $(T\vec{X})$ + $(S\vec{X})$ equations (14) read

$$\frac{d\vec{p}}{dt} = e(\vec{E} - \frac{v_s\vec{v}}{c^2}\left(\vec{u}, \vec{E}\right) - \left(\vec{u} + \frac{v_s\vec{v}}{c^2}\right)Q + \frac{1}{c}\left[\vec{v} + v_s\vec{u}, \vec{H}\right] + \\ + \frac{1}{c}\left(v_s - \left(\vec{u}, \vec{v}\right)\right)\vec{G} + \frac{1}{c}\vec{u}\left(\vec{v}, \vec{G}\right)) \tag{18}$$

$$\frac{dp_s}{dt}=e\left(Q+\left(\vec{u},\vec{E}\right)-\frac{1}{c}\left(\vec{v},\vec{G}\right)-\frac{1}{c}\left(\vec{v},\left[\vec{u},\vec{H}\right]\right)\right) \qquad (19)$$

It was shown that the fields $\vec{E},\vec{H},\vec{G},Q$. can change their signs depending on the sign and agnitude of the acceleration $\dot{u}_S$. Such change of signs of field strengths and, consequently, the change of sign of the Lorentz force may be associated with radiation field's reaction which occurs when a charged particle moves with acceleration.

The change of the sign of the tension in the Exteed space model is of interest from the point of view that under certain conditions the strength of interaction between particles can change its sign, in particular, the strength of attraction between two massive particles can go into a repulsive force, which can be interpreted as a manifestation of "antigravity ".

Probable Coulomb barrier tunneling mechanism within ESM.

In the frame of ESM [5-7] it is possible to offer a new mechanism to tunnel the Coulomb barrier by photons. In the frame of the ESM formalism there are possibility to convert the electric and magnetic field strengths into some new fields, which have new physical properties and can tunnel throw a Coulomb potential barrier.

In order to show it let's consider a plane electromagnetic wave and show that there are transformations, which transform the fields $\vec{E},\vec{H}$ into the fields $\vec{G},Q$ and conversely. With these transformations a wave doesn't disappear, because instead of field components $\vec{E},\vec{H}$ there are appeared nonzero field components $\vec{G},Q$.

For a plane wave, the relations

$$\vec{H}=\left[\vec{k},\vec{E}\right] \qquad (20)$$

are satisfied.

Let the vector $\vec{k}$ is directed along the axis X, then the field components $\vec{E},\vec{H}$ are connected by the relations

$$E_X=H_X=0;H_Y=-E_Z;H_Z=E_Y;$$

We suppose that in empty space the other components of a plane wave are equal to zero.

$$G_Z = G_Y = G_X = 0; Q = 0;$$

Now we perform a variety of rotation and turns in space and see what happens with the components of a plane wave [4,5,7]. At the same time turns into space can be interpreted in two ways - as a transition to a different frame of reference, and as a physical effect that changes the properties of the field.

There are two type of rotations in $G(T; \vec{X}, S)$: the hyperbolic rotations

$$x' = \frac{x + ct\tanh\varphi}{\sqrt{1-\tanh^2\varphi}} = x\cosh\varphi + ct\sinh\varphi$$
$$ct' = \frac{ct + xtanh\varphi}{\sqrt{1-\tanh^2\varphi}} = ctcosh\varphi + xsinh\varphi \tag{21}$$

And spherical rotations

$$x' = xcos\psi + ysin\psi \tag{22}$$
$$y' = -xsin\psi + ycos\psi$$

Let's do two successive transformations of a plane wave:

1. At first, make a rotation in the plane (Y, S) at the corner φ^{YS} . In this case, the field components are transformed with regard to (22) as follows:

$$E'_X = 0; E'_Y = cos\varphi^{YS} E_Y; E'_Z = E_Z$$
$$H'_X = 0; H'_Y = -E_Z; H'_Z = cos\varphi^{YS} H_Z = cos\varphi^{YS} E_Y; \tag{23}$$
$$G'_X = -sin\varphi^{YS}; H_Z = -sin\varphi^{YS} E_Y; G'_Y = G'_Z = 0;$$
$$Q = -sin\varphi^{YS} E_Y$$

Let's take the angle $\phi^{YS} = \pi / 2$, now $\sin\varphi^{YS} = 1; \cos\varphi^{YS} = 0$.

In this case the formulas (23) transforms to:

$$E'_X = 0; E'_Y = 0 \cdot E_Y; E'_Z = E_Z,$$
$$H'_X = 0; H'_Y = H_Y = -E_Z; H'_Z = 0, \quad (24)$$
$$G'_X = -E_Y; G'_Y = 0; G'_Z = 0, \quad Q = -E_Y.$$

2. The second rotation is performed in the plain (ZS) at the angle φ^{ZS}. The field components (24) are transformed with regard to (22) as follows

$$E'_X = 0; E'_Y = 0; E'_Z = \cos\phi^{ZS} \cdot E_Z - \sin\phi^{ZS} \cdot E_Y,$$
$$H'_X = 0; H'_Y = -\cos\phi^{ZS} \cdot E_Z + \sin\phi^{ZS} \cdot E_Y; H'_Z = 0, \quad (25)$$
$$G'_X = -\cos\phi^{ZS} \cdot E_Y - \sin\phi^{ZS} \cdot E_Z; G'_Y = G'_Z = 0,$$
$$Q = -\cos^{ZS} \cdot E_z - \sin\phi^{ZS} \cdot E_Y.$$

We can take in formulas (25) such angle φ^{ZS} that in this case the fields $\vec{E}', \vec{H}'$ are equal to zero.

Non-zero fields will be only

$$G'_X = -\cos\phi^{ZS} \cdot E_Y - \sin\phi^{ZS} \cdot E_Z; \quad (26)$$
$$Q = -\cos^{ZS} \cdot E_Z - \sin\phi^{ZS} \cdot E_Y.$$

The physical meaning of the fields $\vec{G}, Q$ can be associated with the gravitational interaction and the formation of masses of particles [6,7]. As a result of these transformations instead of a plane electromagnetic wave we get an object, which can tunnel of a Coulomb barrier.

The spatial scales and appearance of particle size in the ESM

The problem of localization of wave states is essential for the understanding of quantum processes. Wave-particle duality reflects the fact that, on the one hand, the infinite plane waves is compared to particles and on the other hand, the interaction of particles always occurs locally in a very small area. The existence of such duality in description of electromagnetic processes reflects the fact that, depending on the situation, there are two different formalisms.

One of them is based on energy-momentum vector construction. This vector is associated with localized corpuscular object. With its help one describes the processes of creation and annihilation of photons and their behavior in the environment. Another formalism uses the concept of energy-momentum tensor and adapted primarily to describe the wave properties of objects that are distributed in space. In the frames of the ESM can establish a connection between these two approaches. This will give the possibility to combine the corpuscular and wave approaches to the description of field structures.

In order to it we use the fact that with the help of transformations in the Extended space the massless particles (photons) can acquire a non-zero mass. This mass, following [10] can be connected with some linear scale. And the size of the scale is different for different frequencies. From the other hand one can get the finite size of a particle with the help of the hyperbolic rotations (21). These rotations objectively transform an infinite line into a finite line segment. And it permits us to get a localized finite size massive particle from infinite massless plane wave.

This construction enables one to preserve the relativistic and gauge invariance of the theory; nevertheless that nonzero masses and linear scales are appeared. On the other hand, the same transformations allow us to compare the infinite field structure with some finite scales and s, which also depend on the parameters of the fields. Comparing with each other these scales and masses, can be reconciled vector and wave approaches to the description of electromagnetic phenomena.

Conclusion

In the frame of ESM it is possible to construct a mechanism, which converts a plane electromagnetic wave into a finite size massive object. This object has new physical properties and can tunnel throw a Coulomb potential barrier.

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