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The Theory of Virtual Particles as an Alternative to Special Relativity

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Abstract Special relativity (SR) made it possible to explain a number of physical phenomena, which shows that its postulates: the principle of constancy of the speed of light and the principle of relativity (the latter suggests the invariance of physical laws with respect to Lorentz' transformations reflecting the dependence of mass and size of moving bodies on their speed) are based on the properties of a physical process. It is shown in this paper that such a process is the creation in the physical vacuum of a virtual particles pair by the quantum entity that is a singularity in electric and/or magnetic fields and such properties are properties of this virtual particles pair, in particular, the dependence of its mass and size on the speed of the entity creating the pair. Based on the properties of virtual particles we may assume that theory of virtual particles may be an alternative to SR, it may describe the physical phenomena without using the four-dimensional kinematic formalism, remaining in the framework of the model of three-dimensional space and independent time. A substantiation of this assumption is that the equations describing the physical phenomena derived in SR can be derived as well by taking into account the creation of virtual particles pairs by quantum entities while using the Galilean addition of velocities.

Keywords: *special relativity, virtual particle, Doppler effect for light, spin-orbit interaction, relationship between mass and energy, quantum mechanics*

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1. Introduction

Special relativity (SR) made it possible to explain a number of physical phenomena, some of them as it was formerly supposed might be described only by the formalism of SR (for example, the spin-orbit interaction of electron in an atom, the phenomena relating to optics of moving bodies, in particular, the transverse Doppler effect for light) [1]. The fact that SR may describe physical phenomena correctly shows that SR postulates: the principle of constancy of the speed of light and the principle of relativity (the latter suggests the invariance of physical laws with respect to Lorentz' transformations reflecting the dependence of mass and size of moving bodies on their speed) are based on the properties of a physical process.

It is shown in this paper that such a process is the creation in the physical vacuum of virtual particles pair by the quantum entity, which is a singularity in electric and/or magnetic fields, and such properties are properties of this virtual particles pair. Lorentz transformations reflecting the dependence of mass and size of a moving entity on its speed express essentially the dependence of mass and size of virtual particles pair created by the moving quantum entity on its speed. It is shown also that the second SR postulate (the principle of constancy of the speed of light in all inertial systems) is associated with the interaction of the virtual particles pair that constitutes a photon with virtual particles pairs created by quantum entities that constitute the inertial reference system.

It is shown in this paper that the theory of virtual particles may be an alternative to SR, it may describe the physical phenomena without using the four-dimensional kinematic formalism, remaining in the framework of the model of three-dimensional space and independent time. A substantiation of this assumption is that the equations describing the physical phenomena derived in SR can be derived as well by taking into account the creation of virtual particles pairs by quantum entities while using the Galilean addition of velocities.

Based on such properties of virtual particles pair as the existence of spin, electric dipole moment, mass [2,3], it is possible: 1) to obtain the relationship $U = mc^2$ between energy U and mass m, 2) to obtain the equation for spin-orbit interaction of atomic electron (determining the fine structure of energy levels of atoms), 3) to deduce the equation for the longitudinal and transverse Doppler effects for light (which coincides accurate to β^2 inclusive with the equation describing the Doppler effect in SR [4]), 4) to describe the origin of spin magnetic moment of elementary spin-1/2 fermions [5], 5) to develop a model of magnetic field created by moving charges [6].

Note. It is well-known that derivation of the relationship $U = mc^2$ was performed by Einstein both with and without the mathematical formalism of SR while analyzing the pressure of light on matter [7]. As shown in this work, the Einstein's derivation is based essentially on the properties of virtual particles pair that constitutes the photon.

1.1. Some Properties of a Virtual Particles Pair

In this paper the term "quantum entity" is used. It refers to the entity whose behavior is described by a wavefunction. If the entity has an electric charge and/or dipole magnetic moment and/or dipole electric moment, it is said to be a singularity in electric and/or magnetic fields.

According to contemporary concepts of quantum mechanics, the quantum entity that is a singularity in electric and/or magnetic fields produces in the physical vacuum a pair of oppositely charged virtual particles having spin [2,3]. The number of physical phenomena explained by the properties of virtual particles pairs created by quantum entities is continuously being increased. Among such phenomena are the van der Waals force between two atoms, Casimir effect (attraction between a pair of electrically neutral metal plates), Lamb shift of atomic levels, the spontaneous emission of a photon during the decay of excited atom or excited nucleus, the so called near-field of radio antennas [8,9]. The virtual particles pair has the following properties [2,3].

1) The virtual particles pair is created in the region whose size is of the same order of magnitude as the wavelength of quantum entity that created this pair. The wavelength $\lambdabar_q$ of any quantum entity relates to its momentum p_q as [10]:

$$\lambdabar_q = \hbar / p_q , \tag{1}$$

where $\hbar$ is Planck's constant.

2) The virtual particles pair has spin, S_v, such as

$$S_v = \hbar . \tag{2}$$

The spin of those particles has the same properties as spin of real particles, i.e. has no definite direction and by the magnitude of spin the magnitude of its projection onto a preferential direction is meant: that can be interpreted as a precession of the spin about the preferential direction. The precession frequency ω_v of virtual particles pair is equal to the frequency of wavefunction of quantum entity creating this pair [11]. For example, for virtual particles pair that constitute the photon of frequency ω_{ph} it holds that

$$\omega_v = \omega_{ph} . \tag{3}$$

3) The virtual particles pair has mass m_v that manifests itself, for example, in that the pair of virtual particles that constitutes a photon may be converted in the decay of the latter into a pair of real particles of nonzero mass [10].

4) As follows from experiments, virtual particles conserve energy and momentum [12].

5) In the virtual particles pair the virtual particles have opposite electric charges q_v. The electric properties of virtual particles are the same as those of real particles. From this it follows: first, an electric field $\mathbf{E}_v$ exists between the virtual particles inside the virtual particles pair; secondly, the virtual particles pair is an electric dipole, the electric dipole moment $\mathbf{d}_v$ of the pair is directed oppositely to electric field $\mathbf{E}_v$ [13]:

$$\mathbf{d}_v \uparrow\downarrow \mathbf{E}_v . \tag{4}$$

As it is shown in [6]:

$$\mathbf{d}_v \uparrow\downarrow \mathbf{S}_v . \tag{5}$$

1.2. The Mass-energy Relationship

The photon in the pure state (not interacting with other objects) has circular polarization. That is, the photon electric component $\mathbf{E}_{ph}$ performs circular motion in the plane perpendicular to its velocity $\mathbf{c}$:

$$\mathbf{E}_{ph} \perp \mathbf{c} , \tag{6}$$

with frequency of circulation equal to photon frequency ω_{ph}. As the photon is a quantum entity that is a singularity in electric and magnetic fields, it is itself a virtual particles pair. Consequently, electric field $\mathbf{E}_{ph}$ is electric field $\mathbf{E}_v$ existing between virtual particles inside the virtual particles pair that constitutes the photon:

$$\mathbf{E}_{ph} = \mathbf{E}_v . \tag{7}$$

Thus the precession of $\mathbf{E}_{ph}$, according to (4), (5) and (7), means the precession motion of both spin $\mathbf{S}_v$ and electric dipole moment $\mathbf{d}_v$ of virtual particles pair that constitutes the photon; the frequency of precession ω_v is determined by equality (3). In turn, the precession motion of electric dipole moment $\mathbf{d}_v$ means a circular motion of mass m_v of the pair (that is, of mass of electric dipole) with frequency ω_v. Consequently, the energy W_m associated with mass m_v contains two terms. The first term is the kinetic energy $m_v c^2 / 2$ of translational motion of the center of mass, in which all the mass m_v is assumed to be contained. (An inertial frame of reference where the source of photon is at rest is considered. According to experimental data the speed of light relative to the source is equal to *c*.) The second term is defined [14] as: $J_v \omega_v / 2$, where J_v is the angular momentum connected with the circular motion of mass m_v. Thus the energy W_m is determined as

$$W_v = m_v c^2 + J_v \omega_v / 2 . \tag{8}$$

Equation (8) is written for the virtual particles pair that constitutes a photon, and taking into account the property 4 of virtual particles (Section 1) the following may be accepted: $W_m = U_{ph}$ (U_{ph} is the photon energy).

Taking into account equality (3) and assuming that for the virtual particles pair that constitutes a photon $J_v = \hbar$, equation (8) may be written as

$$U_{ph} = m_v \cdot c^2 / 2 + \hbar \cdot \omega_{ph} / 2. \quad (9)$$

Using the expression for the photon frequency

$$\omega_{ph} = U_{ph} / \hbar \quad (10)$$

in equation (9) we have for m_v:

$$m_v = U_{ph} / c^2. \quad (11)$$

The right side of expression (11) determines the "relativistic" mass m_{ph} of photon [15], and consequently the equation (11) is equivalent to the following equation:

$$m_{ph} = U_{ph} / c^2. \quad (12)$$

Using equations (11) and (12) in equation (9) we obtain the expression for the photon energy in an inertial frame of reference where the source of photon is at rest.

$$U_{ph} = m_{ph} \cdot c^2 / 2 + \hbar \cdot \omega_{ph} / 2. \quad (13)$$

Due to creation of virtual particles pair by the quantum entity, the total mass M of quantum entity of nonzero rest mass equals the sum of two summands: the rest mass m_0 of the quantum entity and mass m_v of virtual particles pair created by the entity.

$$M = m_0 + m_v. \quad (14)$$

If for determining the mass m_v of virtual particles pair created by a quantum entity of nonzero rest mass to use an equation analogous to that used for determining the mass of virtual particles pair that constitutes a photon (equation (11)), then we have:

$$m_v = U_q / c^2, \quad (15)$$

where U_q is the energy of the quantum entity that created the virtual particles pair of mass m_v. If $U_q = m_0 u^2 / 2$ (u is the quantum entity speed), then using equation (15) in equation (14) we have: $M = m_0 + m_0 u^2 / \left(2c^2\right)$. This expression for M at $u \ll c$ accurate to $(u/c)^2$ coincides with Lorentz transformation [1]:

$$M = \frac{m_0}{\sqrt{1 - u^2 / c^2}} = m_0 \left(1 + \frac{u^2}{2c^2} + o\left(\frac{u^2}{c^2}\right)\right),$$

where $o\left(u^2 / c^2\right)$ are summands of a lower order of magnitude than u^2 / c^2.

Note. It is known that Einstein also derived the relationship between energy and mass without using the mathematical formalism of SR while analyzing the pressure of light on matter [7]. His derivation is based on the fact that the momentum which is imposed on matter by a short flash of light is equal to its energy divided by c. This means that in Einstein's derivation the photon momentum p_{ph} equals $p_{ph} = U_{ph} / c$. According to equation (11), $p_{ph} = m_v c$, that is, p_{ph} is defined by the properties of the virtual particles pair that constitutes the photon. Thus one may state that in this case Einstein while deriving the relationship between energy and mass used the properties of virtual particles pair that constitutes the photon.

1.3. The Doppler Effect for Light (Longitudinal and Transverse)

In this Section it will be shown that using the equation (13) for the energy associated with the photon mass, it is possible to describe both the longitudinal and the transverse Doppler effect on the basis of the Galilean addition of velocities, see also [4].

Consider an inertial frame of reference fixed relative to the detector, where the source of light is moving at velocity **v**. The source of light is assumed to be at rest with respect to the Earth, and according to experimental data the speed of light relative to the source is equal to c. It is also experimentally established [10] that the absorption of light occurs in quanta of energy $\hbar\omega_d$, where ω_d is the frequency of the light being detected. If the mass of the detector as well as the mass of the source are great, both the motion of the source due to recoil in the emission of photon and the motion of the detector due to the pressure of light can be neglected. Then in the interaction of the photon and the detector all the energy U_{ph} of the photon in the inertial frame fixed relative to the detector is equal to the detected energy $\hbar\omega_d$, that is, $U_{ph} = \hbar\omega_d$. For determining the frequency ω_d, equations (10), (12) and (13) are used. Taking into account that the first summand in equation (13) defines the kinetic energy of "relativistic" mass of photon and that the detector moves relative to the source at velocity **v**, the equation for determining the frequency ω_d has the form:

$$\hbar\omega_d = \frac{\hbar\omega_{ph}(\mathbf{c} + \mathbf{v})^2}{2c^2} + \frac{\hbar\omega_{ph}}{2}, \quad (16)$$

where ω_{ph} is the photon frequency in the frame of the source of photons. Introducing the vector **w** directed from the source to the detector, $\mathbf{w} = \mathbf{c} + \mathbf{v}$, equation (16) can be expressed as:

$$\hbar\omega_d = \hbar\omega_{ph}\left(\frac{(\mathbf{w})^2}{2 \cdot c^2} + \frac{1}{2}\right). \quad (17)$$

Quantity w/c can be derived from the following equation: $c^2 = (\mathbf{w} - \mathbf{v})^2 = w^2 + v^2 - 2w \cdot v\cos\theta$ (θ is the angle between vectors **w** and **v**). Dividing both sides of this equation by c^2 and denoting $\beta = v/c$ we obtain $(w/c)^2 - 2\beta\cos\theta(w/c) - (1-\beta^2) = 0$. Hence

$$w/c = \beta\cos\theta \pm \sqrt{1 - \beta^2\sin^2\theta} = \sqrt{\beta^2 - \beta^2\sin^2\theta} \pm \sqrt{1 - \beta^2\sin^2\theta}.$$

Taking into account that $w/c>0$ we obtain only one solution: $w/c=\beta\cos\theta+\sqrt{1-\beta^2\sin^2\theta}$ using which in Eq. (17), we obtain:

$$\omega_d=\omega_{ph}\left(1+\beta\cos\theta\cdot(\beta\cos\theta+\sqrt{1-\beta^2\sin^2\theta})-\frac{\beta^2}{2}\right).$$

To an accuracy of β^3 the expression for ω_d may be written as:

$$\omega_d=\omega_{ph}\begin{pmatrix}1+\beta\cos\theta+\beta^2\cos^2\theta-\dfrac{\beta^2}{2}\\ -\dfrac{\beta^3}{2}\cos\theta+\dfrac{\beta^3}{2}\cos^3\theta+o\left(\beta^3\right)\end{pmatrix}, \quad (18)$$

where $o\left(\beta^3\right)$ are summands of a lower order of magnitude than β^3. Equation (18) coincides accurate to β^2 inclusive (at $\vartheta=\pi/2$ accurate to β^3 inclusive) with the equation describing Doppler's effect in SR [1]:

$$\omega_d=\omega_{ph}\frac{\sqrt{1-\beta^2}}{1-\beta\cos\theta}=\omega_{ph}\begin{bmatrix}1+\beta\cos\theta+\beta^2\cos^2\theta-\dfrac{\beta^2}{2}\\ -\dfrac{\beta^3}{2}\cos\theta+\beta^3\cos^3\theta+o(\beta^3)\end{bmatrix}.$$

Let us consider the special cases. If $\cos\theta=0$, the formula describing the transverse Doppler effect follows from Eq. (18): $\omega_d=\omega_{ph}\left(1-\beta^2/2\right)$. If $\cos\theta=1$ or $\cos\vartheta=-1$, the formula describing the longitudinal Doppler effect follows from Eq. (18): $\omega_d=\omega_{ph}\left(1+\beta+\beta^2/2\right)$ or $\omega_d=\omega_{ph}\left(1-\beta+\beta^2/2\right)$ respectively.

Note. In the case discussed above, the source of light is at rest relative to the Earth. However, Eq. (18) will not change if the source does move with respect to the Earth and the photon's speed is made equal to the fundamental constant c with respect to the Earth, with the energy being transformed according to Eq. (16).

1.4. The Spin-orbit Interaction

A pair of oppositely charged virtual particles is an electric dipole, whose electric dipole moment d_v we shall determine according to property 1 of virtual particles pair (see Section 1) as follows [13]:

$$d_v=q_v\lambda\!\!\!^{-}_q, \quad (19)$$

where q_v is the charge of a virtual particle, $\lambda\!\!\!^{-}_q$ is the wavelength of quantum entity creating the pair. In the electric field **E** a moment **M** will act on the electric dipole:

$$\mathbf{M}=\mathbf{d}_v\times\mathbf{E}. \quad (20)$$

We will show, using the electron in a hydrogen atom as an example, that it is the moment **M** that determines the spin-orbit interaction of quantum entity moving in electric field. Let us assume that the specific charge of the virtual particle created by electron is proportional to the specific electron charge (note that the experiments conducted by W. Kaufmann on deflection of beta-rays emitted by radium make one believe that the mass of electron is purely of electromagnetic nature [16]) that is, to e/m_e (e and m_e are respectively the electric charge and mass of electron). Thus $2q_v/m_v=e/m_e$. Using the latter equality, equations (1) and (15), and the expression for Bohr's magneton $\mu_B=e\cdot\hbar\left(2\cdot m_e\cdot c\right)$ in equation (19), we obtain for d_v:

$$d_v=\frac{\mu_B\cdot U_q}{c\cdot p_q}. \quad (21)$$

The energy of electron in a hydrogen atom is equal to its kinetic energy (without taking into account its rest energy), i.e. $U_q=m_qu^2/2$ and $p_q=m_qu$. Using the expressions for U_q and p_q in the equation (21) we obtain:

$$d_v=\frac{\mu_B\cdot u}{2\cdot c}. \quad (22)$$

If for the virtual particles pair created by electron moving at velocity **u** (u<<c) it holds that

$$\mathbf{d}_v\uparrow\uparrow\mathbf{u}, \quad (23)$$

then from equations (20), (22) and (23) it follows: $\mathbf{M}=\dfrac{\mu_B}{2\cdot c}\left(\mathbf{u}\times\mathbf{E}\right)$ and the right side of expression for **M** is the same as that for maximum value of the spin-orbit interaction energy of the electron in a hydrogen atom: $\left(U_{s-o}\right)_{\max}=\left|\dfrac{\mu_B}{2\cdot c}\left(\mathbf{u}\times\mathbf{E}\right)\right|$. In this case **E** is the electric field strength produced by the atomic nucleus at the location of the electron. The equation for U_{s-o} was derived by L. Thomas with due account of general requirements of relativistic invariance (introducing the infinitesimal rotation of electron) [17].

As follows from equations (4), (6) and (7), $\mathbf{d}_v\perp\mathbf{c}$, that is, the deflection angle θ_v between precessing electric dipole moment $\mathbf{d}_v$ of the virtual particles pair that constitutes the photon and the photon velocity **c** equals $\pi/2$. According to (23), at u<<c the deflection angle θ_v between the precessing electric dipole moment $\mathbf{d}_v$ of the virtual particles pair created by electron and electron velocity **u** may be taken to be equal to zero. Consequently, while the speed of quantum entity changes from 0 to **c**, the angle θ_v between precessing electric dipole moment of the virtual particles pair created by this entity and its velocity changes in the range from 0 to $\pi/2$ (Figure 1(a)). That is, the value of $\sin\left(\theta_v\right)$ changes from 0 to 1 and we may introduce the expression:

$$\sin(\theta_v) = u / c. \quad (24)$$

According to equation (5), angle θ_v determines also the deflection angle between precessing spin $\mathbf{S}_v$ of virtual particles pair and velocity **u** of quantum entity that created this pair. Thus projection $(\mathbf{S}_v)_\mathbf{u}$ of spin $\mathbf{S}_v$ on velocity **u** while taking into account the equation (2) is determined by expression:

$$(\mathbf{S}_v)_\mathbf{u} = \hbar \cdot \cos(\pi + \theta_v). \quad (25)$$

Using equation (24) in equation (25) and taking that θ_v varies in the range from 0 to $\pi / 2$, we obtain:

$$(\mathbf{S}_v)_\mathbf{u} = -\hbar \cdot \cos(\theta_v) = -\hbar\sqrt{1 - v^2 / c^2}. \quad (26)$$

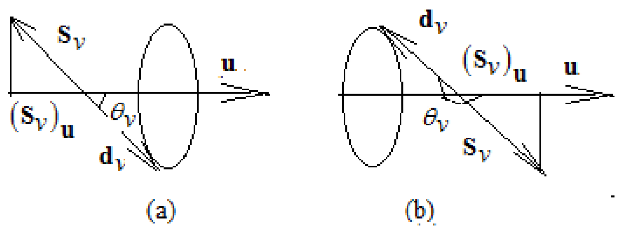

Figure 1. The characteristics of the virtual particles pair created by a charged quantum entity: variant (a) – the quantum entity has a negative charge, variant (b) – the quantum entity has a positive charge. $\mathbf{S}_v$ is spin, $(\mathbf{S}_v)_\mathbf{u}$ is the projection of spin on the direction of velocity **u**, θ_v is the angle between **u** and $\mathbf{d}_v$, $\mathbf{d}_v$ is the electric dipole moment

Note. If the quantum entity has an electric charge, then electric field $\mathbf{E}_q$ of this entity acts on the electric dipole moment of the virtual particles pair created by the entity, that is moment $\mathbf{M}_q = \mathbf{d}_v \times \mathbf{E}_q$ exists. Then the action of moment $\mathbf{M}_q$ results in that the angle θ_v between $\mathbf{d}_v$ and **u** varies in the range from π to $\pi + \pi / 2$, while the speed of positively charged quantum entity changes from 0 to c (Figure 1(b)). In this case, using equation (24) we obtain for $(\mathbf{S}_v)_\mathbf{u}$:

$$(\mathbf{S}_v)_\mathbf{u} = \hbar\sqrt{1 - v^2 / c^2}. \quad (27)$$

Thus according to equations (26) and (27), the value of spin of virtual particles pair created by both positively charged and negatively charged quantum entity decreases in the direction of its motion (at velocity **u**) by $\sqrt{1 - u^2 / c^2}$ times, which is equal to the Lorentz transformation [1].

1.5. The Equalization of Speed of Light in Inertial Systems

The second SR postulate (the principle of constancy of the speed of light) states: in all *inertial systems* the speed of light has the same value when measured with length–measures and clocks of the same kind. In this Section it will be shown that this postulate may be due to the interaction of virtual particles pair created by a photon with virtual particles pairs created by quantum entities that constitute the inertial system (and determine, in fact, its inertial properties). One of the first works containing the physical interpretation of the equalization of the speed of light in inertial systems to a definite value is the work by Fox [18]. The studies by Fox were directed at supporting the Ritz emission theory, according to which the fundamental constant c is the speed of light with respect to the source in the vacuum and the Galilean addition of velocities holds [19]. Fox used the extinction theorem of Ewald and Oseen [20]. The theorem states that if an incident electromagnetic wave traveling at a speed c appropriate to vacuum enters a dispersive medium, its fields are cancelled by part of the fields of the induced dipoles (macroscopically, by the polarization) and replaced by another wave propagating with a phase velocity characteristic of the medium. The incident wave is extinguished by interference and replaced by another wave. The motion of the source and the speed of light relative to it are irrelevant in this theorem. There are, however, some experiments that are not explained by the extinction theorem, for example the experiment performed at CERN, Geneva, in 1964 [21]. In this experiment photons were produced by the source moving at speed of 0.99975c relative to the measurement devices. Photons' speed was measured by time of flight over paths up to 80 meters; within experimental error it was found that the speed of the photons was equal to c relative to the same measurement devices. The extinction theorem, in which the interaction of a photon and a medium takes place by means of the magnetic and electric components of photon, does not explain the results of the experiment. The equalization of the speed of light found in experiments indicates the existence of some other interaction in addition to that.

Taking into account the creation of virtual particles pairs by quantum entities, the extinction theorem must be extended by considering the interaction of virtual particles pair created by the photon and the virtual particles pairs created by quantum entities that constitute the medium. As follows from Section 3, in the equalization of the speed of light the photon energy is transformed according to equation (16).

2. Conclusion

I. Special relativity is based on the properties of virtual particles pairs created by quantum entities in the physical vacuum.

1) For the photon the relationship $U = mc^2$ is a relationship between energy U of the virtual particles pair, which constitutes the photon, and the pair's mass m (c is the group speed of light).

2) The total mass M of a moving quantum entity is the sum of two masses: the rest mass m_0 of this entity and the mass of the virtual particle pair created by the moving quantum entity. If the energy of quantum entity equals its kinetic energy and speed u of the entity meets the condition $u << c$, then expression for M accurate to $(u / c)^2$ coincides with Lorentz transformation:

$$M = \frac{m_0}{\sqrt{1 - u^2 / c^2}} = m_0\left(1 + \frac{u^2}{2c^2} + o\left(\frac{u^2}{c^2}\right)\right),$$

where $o\left(u^2/c^2\right)$ are summands of a lower order of magnitude than u^2/c^2.

3) The value of spin of virtual particles pair created by quantum entity (both positively charged and negatively charged) decreases in the direction of motion by $\sqrt{1-u^2/c^2}$ times, which corresponds to Lorentz transformation.

4) The physical basis of the second SR postulate (the principle of constancy of the speed of light) is the equalization of the speed of light in an inertial system to the same value c as a result of interaction of the virtual particles pair that constitute the photon with the virtual particles pairs created by quantum entities that constitute the inertial system (and determine, in fact, its inertial properties).

II. The theory of virtual particles may be an alternative to SR, it may describe the physical phenomena without using the four-dimensional kinematic formalism, remaining in the framework of the model of three-dimensional space and independent time. A substantiation of this assumption is that the equations describing the physical phenomena derived in SR can be derived as well by taking into account the creation of virtual particles pairs by quantum entities while using the Galilean addition of velocities. Some examples are the following:

1) The precession motion of spin of virtual particles pair that constitutes the photon allows one to deduce the equation $U = mc^2$.

2) The properties of virtual particles pair as an electric dipole allows one to deduce the formula for the spin-orbit interaction of an electron in an atom; this formula determines the fine structure of energy levels of atom.

3) The precession motion of spin of virtual particles pair that constitutes the photon makes it possible to deduce the expression for transformation of frequency (and consequently of energy) of photon when it passes from one inertial system to another inertial system moving relative to the first one at velocity **v**:

$$\hbar\omega_d = \frac{\hbar\omega_{ph}(\mathbf{c}+\mathbf{v})^2}{2c^2} + \frac{\hbar\omega_{ph}}{2}, \qquad (28)$$

where ω_{ph} is the frequency of photon in the first inertial system, ω_d is the frequency of light in the inertial system moving relative to the first one at velocity **v**. In this case the equalization of the speed of light in the second inertial system to the same value c takes place.

4) Using equation (28) for transformation of frequency of photon when it passes from one inertial system to another inertial system moving relative to the first one at a speed **v**, the formula describing the longitudinal and transverse Doppler effects for light can be derived.

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