Relativistic kinematics of two-particle scattering reactions with participation of tachyons

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Abstract. The paper discusses limitations resulting from the laws of conservation of energy and momentum in the processes of elastic and quasi-elastic scattering of relativistic particles with the participation of tachyons, luxons, and bradyons. The obtained expressions for the particle energies are given in the center-of-mass system in the generally accepted Mandelstam variables. Using the laws of conservation of energy and momentum, several channels of reactions of ultrarelativistic particles of high energy in cosmic rays have been considered. It has been shown that on the basis of the expressions obtained, assuming the existence of particles with imaginary masses — tachyons, the effect of "red shift" can be explained.

1. Introduction

Most of the works related to the existence of particles moving faster than the speed of light - tachyons, are philosophical and do not set themselves calculated tasks even at the level of kinematics. For the first time, inherent consequences arising from the kinematics of particles during their disintegration with the participation of tachyons were made by Y. P. Terletsky [1].

The main task of our work is to describe the collisions of high-energy particles with the participation of tachyons without invoking the laws of dynamics specific for each type of interaction. We use a fact that the laws of conservation of energy and momentum are valid for any type of the interaction: weak, strong, electromagnetic and gravitational, that is, they are universal.

As a result of the collisions and decays of the elementary particles, their various transformations occur. The basis of the experimental study of the properties of various particles involved in reactions is the measurement of momentum and energy characteristics. The distribution of secondary particles by momentum and energies, obtained as a result of processing and analyzing the observed events, is a top priority when testing various theoretical models.

The importance and inevitability of the kinematic analysis of data follows from the formulation of the tasks of experimental observation of the interaction of particles. Such an analysis implies obtaining information about the energies, momentum, angles of dispersion of secondary particles at fixed momentum, and primary energies. Characteristics of the particles such as charge, spin, and other internal quantum numbers require special measurements, and we will consider them given when analyzing the pulse characteristics.

2. Materials and methods of research

The basis of the method will be the use of the entire set of conservation laws in force in the world of elementary particles to predict such features of the reactions of their interaction, which can be trusted almost unconditionally. These conservation laws will include the laws of conservation of energy and momentum.

2.1 Tachyons in elementary particle physics and cosmology

The relevance of the chosen topic is confirmed by many modern theories that use tachyons, mainly as a convenient mathematical tool. When creating such theories, tachyons are specially introduced in order to make the vacuum state unstable and to provoke its rebuilding (spontaneous breaking of symmetry), thereby ensuring the appearance of masses on initially massless particles [2].

The tachyons in modern physical theories are considered as some kind of exotic object completely alien to physics. However, in reality, particles with tachyon properties must be dealt with quite often in theory. The problem seems to be very interesting both in general theoretical terms and in terms of possible applications to astrophysics and elementary particle physics.

Starting with the theory of elementary particles, one can point to virtual particles that constitute a necessary element of quantum field theory. Their squared mass is arbitrary and, in particular, can be negative, and the particle mass is imaginary. The superluminal properties of such particles are manifested in the fact that the causal Green's function of the quantized field does not disappear outside the light cone. However, it falls off in this area so quickly that the uncertainty principle makes it impossible to talk about the violation of causality.

Tachyons are included as the most important component of the apparatus of the unified renormalizable theory of weak and electromagnetic interactions based on the “Weinberg-Salam-Glashow model”. In the original versions of string theory, the tachyon appeared in the mass spectrum of particles as the main vacuum state of the string. Just the vacuum state is unstable - its presence is the basis for modifications of string theories. However, sometimes such a modification is made by analyzing the tachyon state itself. Tachyons in this model do not show superluminal properties. The fact is that because of the "wrong" sign of the square of the mass of tachyons, which in this model are Bose particles, their Bose-Einstein condensation occurs in a state with zero momentum. As a result, the sign of the mass square is “corrected”, and tachyons as such cease to exist.

In many modern theories that include spontaneous symmetry breaking (for example, including the Higgs mechanism, as it is included in the Standard Model), there are fields that can be called tachyon in a certain sense.

Tachyon models are capable of explaining inflation in the early stages of the Universe's development and may contribute to the description of new forms of cosmological dark matter in the later epochs of evolution. Tachyon fields have a potential with an unstable maximum at the origin and falling almost to zero as the field tends to infinity. Studies have been conducted tachyon dark energy, depending on the various forms of this potential [3].

It is easy to verify the validity of what was said above on the basis of the canonical Hamiltonian of a scalar nonlinear tachyon field [4]:

$$H = \int d^3x \left[\frac{1}{2}(\varphi^2 + (\nabla\varphi)^2 - M^2\varphi^2) + \lambda\varphi^4\right] \tag{1}$$

where λ is a small coupling constant between the tachyons. The usual definition of the ground state of a system (vacuum) as a state without particles leads to an unstable situation due to the negative sign of the third member. The true ground state of the system corresponds to the nonzero and constant in space and time average value of the field $\langle\varphi\rangle$ arising due to Bose condensation of tachyons. Because of the minimum energy condition $\langle\varphi\rangle = \frac{M}{\sqrt{2\lambda}}$, introducing the “condensate” field $\chi = \varphi - \langle\varphi\rangle$, it is easy to reduce the Hamiltonian to the form:

$$H = \int d^3x \left[\frac{1}{2}(\dot{\chi}^2 + (\nabla\chi)^2 + 2M^2\chi^2) + 2\sqrt{\lambda}M\chi^3 + \lambda\chi^4\right] \tag{2}$$

The resulting replacement $-M^2 \to 2M^2$ really leads to the transition of tachyons into ordinary particles. The tachyon field behaves similarly, subject to Fermi statistics; in this case, Bose condensation of pairs of particles with zero total spin occurs.

The properties of tachyons could, in principle, also detect ordinary particles with “non-minimal” interaction (particles with anomalous magnetic or quadrupole moments, with higher spins, etc.). In a sufficiently strong external field, the square of the effective mass of such a particle may become negative. The simplest example of this kind is a vector particle with an anomalous magnetic moment μ in a magnetic field H parallel to its momentum. The particle dispersion law $E = c\sqrt{p^2 + M^2c^2 \pm 2M\mu H}$ acquires a tachyon character in a sufficiently strong field.

The examples given, the number of which could be multiplied, are taken from quantum field theory and are rather special in nature. It turns out that in macroscopic physics there are many examples of a “tachyon-like” situation which is quite typical for unstable systems. The negative "square of mass" is contained in the dispersion law of those oscillations that lead to the buildup of the system:

$$\omega^2 = {c'}^2 k^2 - \Gamma^2 \tag{3}$$

Here ω and k are the frequency and wave vector of oscillations, c' is the characteristic speed, and Γ is the inverse time of instability development. Like tachyons, the group velocity of the wave is more than c. On the other hand, at small k, the frequency acquires imaginary values, which corresponds to an increase in oscillations with time.

In addition to all the above, one can give an example [5] relating to the propagation of an electromagnetic wave in a medium with inverse level population. Let the particles of the medium be two-level systems with energy levels $E_{1,2}$, and the transition frequency $E_1 - E_2$ is considered small compared with the frequency of the wave. The population of levels referred to the unit volume, we denote by $N_{1,2}$. Then the inverse population corresponds to a positive value of the parameter $\xi = (E_1 - E_2)(N_1 - N_2)$. The vectors of the electric field of the wave $\boldsymbol{E}$ and the polarization of the medium $\boldsymbol{P}$ are related by the relation $\Box \boldsymbol{E} = 4\pi \ddot{\boldsymbol{P}}$. On the other hand, the equations of motion give the relation $\ddot{\boldsymbol{P}} = -2\xi\, |d_{12}|^2 E$, where d_{12} is the matrix element of the dipole moment. Thus, we obtain the dispersion relation with $c' = c$ and $\Gamma^2 = 8\pi\xi|d_{12}|^2$. The negative square of the effective photon mass in a medium with inverse population reflects the instability of the system with respect to the transition to the lower level and the generation of a coherent electromagnetic wave.

Tachyon gas has the characteristic properties of so-called dark (hidden) matter. On the one hand, it is not possible to detect a separate particle of dark matter. On the other hand, dark matter forms huge halos around galaxies with an almost constant mass distribution density inside the halo. The existence of such halos is detected by their gravitational effects on the speeds of stars on the periphery of the galaxy. Tachyons have similar properties. A separate tachyon cannot be detected. The tachyon gas has an almost constant mass density in the gravitational field of the galaxy.

States similar to tachyons arose in the theory before the appearance of this term [6] when considering various generalizations of the known equations. So, for example, in 1952, Corben proposed adding a pseudoscalar mass [7] to the Dirac equation describing particles with left and right helicities:

$$\left(\gamma^\mu \frac{\partial}{\partial x^\mu} + m_0 + i m_c \gamma_5\right)\psi = 0 \tag{4}$$

When considering specific problems, the Dirac-Corben equation led to the same predictions as the Dirac equation. It was shown [8] that there is a unitary transformation

$$\psi_C = U\psi_D \tag{5}$$

$$U = \frac{1}{\sqrt{2}}\left(1 + \frac{m_0}{m}\right)^{1/2}\left[1 + i\frac{m_c}{m}\left(1 + \frac{m_0}{m}\right)^{-1}\right] \tag{6}$$

the Dirac-Corben equation to the Dirac equation, in which the mass term takes the form

$$m = (m_0^2 + m_c^2\,)^{1/2} \tag{7}$$

That is, the square of the mass can take different values depending on the size of the pseudoscalar mass m_c:

$$m^2 = m_0^2 + m_c^2 \tag{8}$$

For $m_0 \neq 0$ and $m_c = i\mu$ $(\mu > 0)$, for the effective mass we get the expression:

$$m = \pm\ (m_0^2 - \mu^2\ )^{1/2} \tag{9}$$

Thus, here a particle can be a tachyon (v>c) with $m_0 < \mu$, a luxon (v=c) with $m_0 = \mu$, and a bradyon (v<c) with $m_0 > \mu$.

For an illustration of the coexistence of both wave and particle, de Broglie suggested [9] that the physical wave $u(\vec{r},t)$ (unlike the fictitious statistical wave $\psi(\vec{r},t)$ in conventional quantum mechanics) can be represented as a superposition of two physical waves. One of them is a highly localized (singular) region of the u_0 wave with a very high concentration of energy, that is, a corpuscle, the other is a physical wave ϑ having a very small amplitude throughout the propagation region that can be associated with a non-physical fictitious wave ψ.

De Broglie came up with the idea of treating a particle as a small moving clock. In this case, the observers of the experiment were the elementary particles themselves, and not outsiders. Such particles interact with each other by exchanging wave signals. He attributed to each particle an internal periodic process with several functions. The first function was that this process served as a measure of internal time, the second was to ensure the creation of wave signals through which the interaction takes place. Since the rhythm of a particle sets the time scale and is an internal clock, therefore, only a particle can be oriented in time. De Broglie did not know the mechanism of internal oscillations, but he took it for granted. The frequency of this internal process, he describes the formula, guided by one of the fundamental ideas of the theory of quanta:

$$m_0 c^2 = \hbar\omega_0 \tag{10}$$

The formula is valid in the laboratory frame of reference, but it enters into complete contradiction when using a relativistic theory, when moving to another system, since it is not a Lorentz-invariant expression.

In the resolution of this contradiction, Louis de Broglie comes to the concept of a stationary wave. He suggested that there is some oscillatory process occurring somewhere inside the particle at the frequency ω_0. This process somehow goes outside and at every point of the space surrounding a given particle, it excites oscillations of equal frequency.

This statement, in our opinion, can be given a rigorous mathematical formulation. Let for a particle at rest in all points of space we observe an oscillatory process described by an exponential: $e^{i\omega_0 t}$.

That is, at each point in space, infinitely distant from the particle, an oscillatory process occurs (but not a traveling wave) with a frequency ω_0. All these processes have the same phase in all space. However, such behavior is characteristic only of the particle's own reference system, in which we observe only oscillations, but not a wave.

According to the relativistic description, the time changes according to the Lorentz transformations as:

$$t \quad \rightarrow \quad \frac{t - \frac{\beta x}{c}}{(1-\beta^2)^{1/2}} \quad , \qquad \text{where} \quad \beta = \frac{v}{c} \tag{11}$$

Then the equation for a stationary wave in any reference system will be rewritten in the form:

$$e^{i\omega_0 t} \quad \rightarrow \quad e^{i\frac{\omega_0}{(1-\beta^2)^{1/2}}\left[t-\frac{\beta x}{c}\right]} \;=\; e^{i\frac{\omega_0}{(1-\beta^2)^{1/2}}\left[t-\frac{vx}{c^2}\right]} \;= \\ =\; e^{i\frac{\omega_0}{(1-\beta^2)^{1/2}}t\left[1-\frac{v^2}{c^2}\right]} \;=\; e^{i\frac{\omega_0}{(1-\beta^2)^{1/2}}t[1-\beta^2]} \tag{12}$$

Therefore, we find that the frequency in the moving reference frame transforms in the same way as the mass

$$\frac{m_0c^2}{(1-\beta^2)^{1/2}} = \frac{\hbar\omega_0}{(1-\beta^2)^{1/2}} \tag{13}$$

Therefore, the formula $m_0c^2 = \hbar\omega_0$ can finally be rewritten in the relativistic form:

$$mc^2 = \hbar\omega \tag{14}$$

Let us describe some of the consequences of the theory presented by de Broglie [9], [10].

In the formula (12) we have:

$$\frac{c^2}{v} = V > c \qquad , \qquad v \cdot V = c^2 \tag{15}$$

where V is the phase velocity of a de Broglie wave moving faster than the speed of light (tachyon), v is the group velocity, the velocity of the corpuscle (bradyon).

These two velocities must be strictly separated according to their physical meaning, but at the same time they are connected by the formula $c^2 = v \cdot V$.

Using formula (15) of the coupling of the phase velocity of the wave and the velocity of propagation of the singularity, we obtain that the stationary wave propagates with the phase velocity V and has a wavelength:

$$\lambda = V \cdot T = V \cdot \frac{2\pi}{\omega} = \left[\omega = \frac{mc^2}{\hbar}, \frac{c^2}{v} = V\right] = 2\pi\frac{\hbar}{mv} = \frac{h}{p} = \lambda_Б \approx \frac{h}{m_0v}, \quad v \ll c \tag{16}$$

Due to the interconnection of the phase velocity of the wave ($V > c$) of de Broglie and the velocity of the particle ($v \ll c$), while deriving the wavelength of de Broglie (16), we move from one speed to another.

The speed of the de Broglie stationary wave (phase velocity), as well as the speed of the tachyon, is always greater than the speed of light, which in turn indicates a possible connection between the theory of tachyons and the de Broglie wave.

Thus, despite its unusual properties, there is every reason to consider tachyon not just a convenient tool of the theory, but a real part of the physical picture of the world.

2.2 Formulation of the problem

As is known, particles with mass move with a velocity v_B lower than the speed of light. We will call them bradyons and denote the letter *B*. Massless particles (photons, neutrinos) move with the speed of light $v_\Lambda = c$. They will be called luxons Λ.

In addition, the special theory of relativity allows the existence of particles moving always faster than the speed of light (tachyons), which will be denoted by the letter T.

In the development of the ideas set forth in [1], where reactions involving tachyons (T), bradyons (B) and luxons (Λ) of the form

$$B' \rightleftarrows B + T, \qquad B' \rightleftarrows \Lambda + T, \qquad \Lambda \rightleftarrows B + T, \qquad T' \rightleftarrows B + T \tag{17}$$

we consider two-particle reactions involving bradyons, luxons, and tachyons and their transformation into other particles with a greater or smaller mass of the form

$$1 + 2 \rightleftarrows 3 + 4 \tag{18}$$

Here, any of the particles, or two, three or even all four, can be tachyons. In this paper, we assume the speed of light *c* is equal to 1.

The main kinematic characteristic of a particle in the physics of interactions of elementary particles is the 4-vector of the pulse energy $\mathbb{P}$, whose time component is the total energy of the particle p_0, and the spatial components are the components of the 3-momentum of the particle $\vec{p}$.

From the point of view of kinematics, particles are completely characterized by the values of energy and momentum, the combination of which determines the 4-momentum. The latter during the Lorentz transformations is transformed as a 4-vector. The full 4-pulse system is saved. These very simple facts are the basis of the kinematics of elementary processes of scattering and decay of particles.

In our work, we use the metric (+1, -1, -1, -1), $x^\mu = (x^0, \vec{x})$, $x_\mu = (x_0, -\vec{x})$, in which "co" and "contra "- variant components of vectors are different. The following notation is used in this paper: the

4-energy-momentum vector $P^{\mu} = (E, \vec{p}) = (p_0, \vec{p})$, which we will denote further $\mathbb{P}$. In the adopted metric $\mathbb{P}^2 = E^2 - \vec{p}^2$. Here and later we adopt *c = 1*.

The law of conservation of the 4-vector energy-momentum in an arbitrary coordinate system for the process (18) has the form:

$$\mathbb{P}_1 + \mathbb{P}_2 = \mathbb{P}_3 + \mathbb{P}_4 \tag{19}$$

Here for each of the particles we have the Einstein relations:

$$\mathbb{P}^2 = E^2 - \vec{p}^2 = m^2 \tag{20}$$

Possible variants:

$$m^2 > 0\,, \qquad m^2 = -\mu^2 < 0\,, \qquad m^2 = 0 \tag{21}$$

For bradyons, the Einstein relation is:

$$\mathbb{P}_B{}^2 = m_B{}^2 > 0\,, \qquad that\ is \quad E_B{}^2 - \vec{p}_B{}^2 = m_B{}^2 > 0 \tag{22}$$

Here, the bradyon energy E_B is always a real positive value.
Similarly for luxons we have:

$$\mathbb{P}_\Lambda{}^2 = m_\Lambda{}^2 = 0 \qquad or \qquad E_\Lambda{}^2 - \vec{p}_\Lambda{}^2 = 0 \tag{23}$$

The energy of luxons we shall consider positive.

For tachyons ($m = i\mu, \quad \mu > 0$):

$$\mathbb{P}_T{}^2 = -\mu^2 < 0 \qquad or \qquad E_T{}^2 - \vec{p}_T{}^2 = -\mu^2 < 0 \tag{24}$$

This implies

$$E_T{}^2 = \vec{p}_T{}^2 - \mu^2\,, \qquad E_T = \pm\left(\vec{p}_T{}^2 - \mu^2\right)^{1/2} \tag{25}$$

Of the two possible signs of energy in (25), we choose positive (as for ordinary particles), that is

$$E_T = +\left(\vec{p}_T{}^2 - \mu^2\right)^{1/2} \tag{26}$$

which means always $P_T{}^2 > \mu^2$.

Based on the laws of conservation of energy and momentum (4 scalar equations) according to (19) we have:

$$E_1 + E_2 = E_3 + E_4 \equiv E \tag{27}$$

$$\vec{p}_1 + \vec{p}_2 = \vec{p}_3 + \vec{p}_4 \tag{28}$$

We assume that the characteristics of the initial particles (8 scalar quantities) that interact with each other are known: m_1, m_2, $\vec{p}_1$, $\vec{p}_2$. Values to be found: m_3, m_4, $\vec{p}_3$, $\vec{p}_4$.

Thus, we have eight unknown scalar quantities satisfying four scalar equations (27) - (28) and four equations (20). Since the conservation laws are valid for all types of interactions of elementary particles, the resulting formulas turn out to be universal and do not depend on the dynamics of interactions.

All scattering reactions of elementary particles can be reduced to three types. **The first type is elastic reactions** of scattering of particles $1 + 2 \to 1' + 2'$. This is the simplest binary scattering reaction. With this type of scattering as a result of the collision, the momenta and energies of the initial particles are changing, and all other characteristics, such as mass, spin, and charge, are not changing. The formation of new particles does not occur. **The second type is quasi-elastic reactions** when two final particles are formed and their types differ from the type of initial particles. However, it is also possible that a variety of one of the secondary particles coincides with the primary one. **The third type is the inelastic interaction reactions**, as a result of which more than two particles are formed. The number of secondary particles at modern accelerator energies can reach several tens and even hundreds, forming jets of the elementary particles.

Reactions of interaction of elementary particles are studied in selected reference systems. This is often associated with the features of experimental facilities and with the theoretical convenience of describing the interaction process. **The laboratory reference system** corresponds to the standard formulation of experiments at the accelerators when a beam of particles of type 1 hits a fixed target consisting of particles of type 2. **In the center-of-mass system**, the colliding particles have equal but opposite opposite impulses in the module. That is, $\vec{p} = \vec{p}_1 + \vec{p}_2 = \vec{p}_3 + \vec{p}_4 = 0$. In practice, the center of mass system is used when conducting experiments on colliding beams. If the experiment was performed in a laboratory system for convenience of theoretical analysis, all kinematic characteristics are transformed to the center of mass system, where the kinematic picture of the reaction looks more symmetrical. That is why we consider our task in the center of mass system. For convenience of calculations, invariant variables s, t, u are introduced in scattering problems [11].

By definition

$$s = (\mathbb{P}_1 + \mathbb{P}_2)^2 = m_1^2 + m_2^2 + 2E_1 m_2 \tag{29}$$

in the laboratory reference system.

Then

$$s = (E_1^* + E_2^*)^2 \tag{30}$$

in the center of mass system. The values in the center of mass system are marked with an asterisk. The physical meaning of this variable **s** is the square of the total energy in the center of mass of the reaction. It characterizes the initial state of the total system.

The variables squares of the transmitted 4-momentums **t** and **u** are:

$$t = (\mathbb{P}_1 - \mathbb{P}_3)^2 = (\mathbb{P}_2 - \mathbb{P}_4)^2 \tag{31}$$

$$u = (\mathbb{P}_1 - \mathbb{P}_4)^2 = (\mathbb{P}_2 - \mathbb{P}_3)^2 \tag{32}$$

The variables s, t, u are called Mandelstam invariants. They are connected by a linear invariant relation

$$s + t + u = m_1^2 + m_2^2 + m_3^2 + m_4^2 \tag{33}$$

In the further reasoning, we will use only the invariant s, since the problem of finding the scattering angles of elementary particles with the participation of tachyons was not considered at this stage.

In the center of mass system, the total momentum of the colliding particles is zero, and the particle energy is expressed in terms of the invariant s and mass as follows [12]:

$$E_1^* = \frac{s + m_1^2 - m_2^2}{2\sqrt{s}}, \qquad E_2^* = \frac{s + m_2^2 - m_1^2}{2\sqrt{s}} \tag{34}$$

$$E_3^* = \frac{s + m_3^2 - m_4^2}{2\sqrt{s}}, \qquad E_4^* = \frac{s + m_4^2 - m_3^2}{2\sqrt{s}} \tag{35}$$

3. Results and discussion

3.1 Energetic expressions for reaction products and consequences for cosmology

Let us give examples of the most interesting, from our point of view, reactions. At first we consider a two-particle quasi-elastic scattering of a bradyon on a bradyon followed by the birth of two tachyons:

$$B_1 + B_2 \;\rightarrow\; T_1 + T_2 \tag{36}$$

Using the previously obtained relations for the energy of the initial and final particles (34) and (35), we write:

$$E_{B_1}^* = \frac{s + m_{B_1}^2 - m_{B_2}^2}{2\sqrt{s}}, \qquad E_{B_2}^* = \frac{s + m_{B_2}^2 - m_{B_1}^2}{2\sqrt{s}} \tag{37}$$

$$E_{T_1}^* = \frac{s + \mu_{T_2}^2 - \mu_{T_1}^2}{2\sqrt{s}}, \qquad E_{T_2}^* = \frac{s + \mu_{T_1}^2 - \mu_{T_2}^2}{2\sqrt{s}} \tag{38}$$

From (38) it can be concluded that a tachyon with a larger mass will have less energy than a tachyon with a smaller mass, that is, a greater part of the energy is carried away by a lighter tachyon. This is absolutely not the case at birth of particles of real mass, where most of the energy is carried away by a more massive particle (and a large part of the momentum by a light particle).

Let us consider the reaction of quasi-elastic scattering of a luxon on a bradyon with the birth of a luxon and tachyon:

$$\Lambda + B \;\rightarrow\; \Lambda' + T \tag{39}$$

We will rewrite the expressions for the energies of the final and initial particles in the following form:

$$E_{\Lambda}^{*} = \frac{s - m_B^2}{2\sqrt{s}} \quad , \qquad E_{B}^{*} = \frac{s + m_B^2}{2\sqrt{s}} \tag{40}$$

$$E_{\Lambda'}^{*} = \frac{s + \mu_T^2}{2\sqrt{s}} \quad , \qquad E_{T}^{*} = \frac{s - \mu_T^2}{2\sqrt{s}} \tag{41}$$

As can be seen from the obtained expressions (41), luxon acquires energy, which can be interpreted as a “blue shift”. At present, it is considered in cosmology that light coming from areas with a weaker gravitational field experiences a gravitational blue shift [13]. As you can see, the kinematics does not prohibit the processes leading to the effect of blue displacement in the scattering of luxons on bradyons with the subsequent birth of the tachyon.

Consider the reaction of quasi-elastic scattering of bradyon on a luxon with the subsequent birth of bradyon and tachyon:

$$B + \Lambda \quad \rightarrow \quad B' + T \tag{42}$$

Expressions for energies take the forms:

$$E_{B}^{*} = \frac{s + m_B^2}{2\sqrt{s}} \quad , \qquad E_{\Lambda}^{*} = \frac{s - m_B^2}{2\sqrt{s}} \tag{43}$$

$$E_{B'}^{*} = \frac{s + m_{B'}^2 + \mu_T^2}{2\sqrt{s}} \quad , \qquad E_{T}^{*} = \frac{s - \mu_T^2 - m_{B'}^2}{2\sqrt{s}} \tag{44}$$

From equations (44), we conclude that bradyon, when interacting with luxon at birth of the tachyon acquires energy, which in turn can be interpreted as a mechanism for accelerating cosmic rays. Therefore, it can be assumed that fundamentally new, extremely powerful energy sources can be realized in space if particles of imaginary mass actually exist in nature. Indeed, particles with energies of billions of TeV or several exaectronvolts, so-called «OMG (Oh-My-God) particles, were recorded in the atmosphere, whose birth mechanism is discussed [14]. Bradyons in the presence of such reactions for billions of years all the time accelerated and acquire enormous energies. Such a high-energy particle, entering the atmosphere of the Earth, as a result of multiple cascade reactions creates a wide air shower of secondary subatomic particles.

Even more interesting is the reaction of the quasi-elastic scattering of a luxon on a tachyon with the birth of luxons and bradyons:

$$\Lambda + T \quad \rightarrow \quad \Lambda' + B \tag{45}$$

$$E_{\Lambda}^{*} = \frac{s + \mu_T^2}{2\sqrt{s}} \quad , \qquad E_{T}^{*} = \frac{s - \mu_T^2}{2\sqrt{s}} \tag{46}$$

$$E_{\Lambda'}^{*} = \frac{s - \mu_{\boldsymbol{B}}^2}{2\sqrt{s}} \quad , \qquad E_{B}^{*} = \frac{s + m_{\boldsymbol{B}}^2}{2\sqrt{s}} \tag{47}$$

Thus, assuming that outer space is filled with a tachyon gas, when luxons passe through it and the subsequent birth of bradyons (real mass particles), the luxons will lose their energy, thereby reducing their frequency, which can be interpreted as a "red light shift". Currently, the cosmological redshift is associated with the Doppler effect, which depends on the dynamic removal of sources from each other and, in particular, from our galaxy. To explain this fact, a hypothetical dark energy was introduced which is inaccessible to direct observations and has exotic properties. However, "the nature and structure of dark energy is completely unclear, and, thus, the difficulties are shifted from the field of the theory of gravity and cosmology to the physics of the microworld" [15]. In our work, the results obtained from simple kinematic expressions allow us to look for another angle into this problem.

4. Conclusion

So, assuming that only the laws of conservation of energy and momentum are fulfilled, the following results are obtained:
1. In the interaction of two bradyons with the subsequent birth of two tachyons, a tachyon with a larger mass will have less energy than a tachyon with a smaller mass.
2. At the birth of a luxon with a tachyon, in the reactions of interaction of a luxon with a bradyon, luxon acquires energy (blue displacement).
3. When quasi-elastic scattering of bradyon on luxon, followed by the birth of bradyons and tachyons, the bradyon acquires energy (high-energy cosmic rays).
4. When luxon fluxes pass through the tachyon gas it can provokes reactions with the creation of bradyons, which in its turn provokes the energy lost of initial luxon, its reducing frequency looks like the "red shift phenomenon".

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