Uncertainty relations describing the short-term violations of Lorentz invariance: superluminal phenomena, particles transformations

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The refinement and specifications of time-energy uncertainty relations have shown that the experimentally observed phenomena of superluminal signaling are describable by such their form: \( \Delta E \Delta \tau \geq \pi \hbar \), where both standard deviations are negative. When \( \Delta \tau < 0 \), these evanescent photons would be instantly tunneling from one light cone into another on the distance \( c|\Delta \tau| \). (This assertion, previously proved via dispersion relations, is described here by the temporal parameters of process.) Special forms of these relations describe the transmutation of particles into their partners of bigger mass, in \( K^0 \) and \( B^0 \) cases and at the \( \nu \) ‘s transmutations. Thus, the violations of relativistic causality by evanescent particles can be considered as the tunneling, as an analog of the short-term violation of conservation laws at virtual transitions. The absence of Lorentz invariance at such transitions can, probably, allow violations of some other symmetries.

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I. INTRODUCTION

In the last years some possibilities of violations of the Lorentz invariance and relativistic causality are actively discussing. On the one hand there are the numerous experimental observations of superluminal, faster-than-\( c \), signal transfer at low energies (e.g. the reviews [1]). On the other hand the discussions of such possibilities in the high energy physics are conducted, they are connected with \( CP \) or even \( CPT \) violations and are usually considered via addition of new terms in the standard Lagrangian of field theories (e.g. [2]) and so on.

As it is proved in [3] the experimental data of superluminal transfer are restricted to the condition: Superluminal transfer of excitations (jumps) through the linear passive substance can affected by nothing, but the instantaneous tunneling of virtual particles; distance of tunneling is of order of half wavelength corresponding to energy deficit relative to the nearest stable (resonance) state.

This condition can be expressed as
\[
(\Delta E \Delta \tau)_{\text{stable}} \geq \pi \hbar, \quad (1.1)
\]
where both standard deviations \( \Delta E \) and \( \Delta \tau \) must be simultaneously negational and which formally looks like an extraordinary special form of the uncertainty relations. The negativity of \( \Delta \tau \) can be interpreted as an advancing emission or as the instantaneous transferring, i.e. the tunneling through classically forbidden space-time regions, from one light cone into another.

Thus some questions should be considered: what sense can have such seemingly violations of the general principle of locality and relativistic causality of the theory, and thereafter: is the form (1.1) universal and so can it predict analogical peculiarities in another phenomena, or such forms must be specialized for different processes if they exist?

What can we say, firstly, if the apparent Lorentz violations in low and high energy ranges exist, but they can be expressed in the form or via some analogs of uncertainty principle?

Let’s remember that although the virtual transitions violate the conservation laws, short-termlly or on the distances of tunneling, in the scope of uncertainty principles, it does not present difficulties and does not provoke discussions: it is well known that such violations do not lead to possibilities of perpetuum mobiles construction, etc. And if analogously the deviations from the Lorentz invariance would be restricted by some form of quantum uncertainties or indeterminacies, it would only mean that along with virtual states or particles the evanescent states or particles can be manifested, but it does not mean any possibility of time arrow transformation (the common or primitive causality). Such phenomenon would demonstrate only the existence of one more quantum peculiarity of Nature, the specific possibilities of quantum tunneling between light cones and so on, and does not require any revision of the relativity’s principles.

For an answer to the second question it must be taken into account that the energy-time uncertainty principle is of more complicate nature than others. The Heisenberg canonical form \( \Delta A \cdot \Delta B \geq \hbar /2 \), which is obviously cited as the general form of uncertainty relation, is the oversimplified one and many years ago was generalized on superconcept relations by Robertson [4] and Schrödinger [5]. It seems that the most constructive form of such generalization was expressed by Mandelstam and Tamm [6]. They had shown, in particular, that for decay processes the energy-time uncertainties must be expressed as
\[
(\Delta E \Delta \tau)_{\text{decay}} \geq \pi \hbar /4. \quad (1.2)
\]
In the recent years the attention to such forms was attracted by investigations of so named squeezed light phenomena (e.g. [7] and references therein).

All it means the necessity of reconsideration of these uncertainty relations.

As the relation (1.1) is of a new form and can be directly tested by experiments, we shall begin with its outline in the Section 2. Its deduction in [3] for processes of superluminal transfer of excitations requires the complicated dispersion relations, which can overshadow its direct
sense. Therefore its overview follows the temporal functions describing the time delay at scattering process and the duration of particle formation (dressing), i.e. all considerations goes via the kinematics of transferring. The deduction in [3] was executed for photons only, and for widening such approach the temporal functions for massive particles needed for further consideration are written out in the Section 3.

The general consideration of uncertainty relations in the Section 4 confirms both forms, (1.1) and (1.2), for corresponding processes. Along with them it leads to more customary, but more specified relation
\[(\Delta E \Delta t)_{\text{transmut}} \geq \hbar/2 \quad (1.3)\]
for the processes of particles transmutation. The application of this relation to processes of neutral mesons and neutrinos transmutations is briefly considered in the Section 5. This examination would demonstrate that the transmutations could be interpreted as the transitions into higher energy (mass) state only, and just therefore, for example, the transitions of muonic neutrino into electronic one can be absent or be suppressed. This relation leads also to a new estimation of the neutrino mass.

These results and certain further perspectives are summed in the Conclusions.

II. TEMPORAL FUNCTIONS FOR MASSLESS PARTICLES

The description of "superluminal" processes can be performed via two analytically connected temporal functions.

The time duration of particle (photon) delay in the course of elastic scattering is determined by the Wigner-Smith expression via the logarithmic derivative of corresponding matrix element (e.g. [8]):
\[\tau_1 = \text{Re}(\partial/\partial \omega) \ln S(\omega, k). \quad (2.1)\]

This magnitude is related to the scatterer and describes its state only. (There are many different definition of delay duration, e.g. the reviews [9], but for our discussion the general definition (2.1) seems enough.) Along with this temporal magnitude the duration of gradual formation (the "dressing") of formed particle should be determined. Such problem was initially considered, in the very general form, by Bohr and Rosenfeld [10]. In the connection with experiments such notion had been introduced for the first time by I. Frank [11] in the semiclassical theory of Čerenkov radiation: without it the emission of discrete quanta at the uniform motion of charge, even with the superluminal velocity in medium, was absolutely non-understood. By present time some analogous problems compose the special direction in the radiation and scattering theory (e.g. the review [12]).

For our purposes the duration of formation can be expressed in the form similar (2.1) (its substantiation and more detailed statements are given in [13]):
\[\tau_2 = \text{Im}(\partial/\partial \omega) \ln S(\omega, k). \quad (2.2)\]

The joining of these two expressions leads to the equation:
\[\frac{\partial}{\partial \omega} S(\omega, k) = \tau S(\omega, k) \quad (2.3)\]
which can be considered as the analog of the Schrödinger equation for $S$-matrix of interaction with a temporal operator $\tau$ that plays the role of Hamiltonian.

The consideration of temporal functions of QED would begin from the temporal features of the simplest photon causal propagator (the Feynman gauge, $\eta \to 0+$):
\[D_\omega(\omega, k) = 4\pi/(\omega^2 - k^2 + i\eta), \quad (2.4)\]
which leads to the expressions for durations of delay and of formation:
\[
\begin{align*}
\tau_1 &= -2\pi\omega \delta(\omega^2 - k^2) \to -\pi\delta(\omega - |k|), \\
\tau_2 &= 2\omega/(\omega^2 - k^2) \to 1/(\omega - |k|). 
\end{align*}
\]

As the propagator (2.4) does not include parameters of scatterer, the function $\tau_1$ descriptively shows that photon can be absorbed or emitted only completely; already this form contradicts possibility of its gradual evolution. The function $\tau_2$ qualitatively corresponds to the uncertainty principle, is twice bigger its usual form and shows the possibility of retarded, at $\omega > |k|$, or advanced, at $\omega < |k|$, emissions of photon: just the advanced form must be interpreted as the instantaneous jump onto corresponding distance. (Remember in this connection that the causal propagators overstep the limits of cone.)

These definitions are of the general character. Let’s concretize them for superluminal processes by considering the $(\omega, r)$-representation, from which would be deduced the distances of "superluminal" transitions. It must be noted only that the temporal functions $\tau(\omega, r)$ and $\tau(\omega, k)$ are not simply connected by the Fourier transformation; their interrelation is partly considered in [13], but here we shall use both for the qualitative analysis.

The causal propagator of QED $D_\omega(t, r) = \mathcal{D}(t, r) + i\mathcal{D}_1(t, r)$, where the first Green function is supported in the light cone, but the second one oversteps its limits and therefore is of the prime interest for us. In the mixed representation $D_\omega(\omega, r) = (1/2\pi) \sin(\omega|r|)$ and the corresponding temporal function:
\[\tau(\omega, r) = (\partial/\partial \omega) \ln D_\omega(\omega, r) = -i\pi\cot(\omega r) \quad (2.6)
\]
or
\[\tau_1(\omega, r) = 0; \quad \tau_2(\omega, r) = -r\cot(\omega r). \quad (2.6')\]

These expressions implicitly show, that such process can go without delay and that under definite values of $\omega r$ the duration of formation can be negational, i.e. along with the "normal" transitions (2.6) can describes the instantaneous jumps of transferred excitation.

The Coulomb field infinitely, as the static one, is in the "undressed" state, and therefore the subtraction of the Coulomb pole $1/\omega$ in (2.6') is needed. This subtraction can be performed with the decomposition of cotangent:
\[\cot(x) = 1/x + \sum_{n=1}^{\infty} 2x/(x^2 - \pi^2 n^2).\]

It leads to the renormalized expression for $\tau_2$:
\[\tau_2^{\text{renorm}}(\omega, r) = -\sum_{n=1}^{\infty} 2\omega r/(\omega^2 r^2 - \pi^2 n^2), \quad (2.7)\]
which shows that the first pole of (2.7) is at the point $\omega r = \pi$ (near to resonance the substitution $\omega \to \Delta\omega$ can
be made). From (2.7) follows the (minimal) formation path for photon:
\[ \Delta \ell \approx \pi c/|\Delta \omega|. \]  
(2.8)

As this process is instantaneous, it corresponds to the jump of photon at the act of formation on the distance \( \pi c/|\Delta \omega| \) or \( \lambda/2 \), if \( \Delta \omega \to \omega \). Thus, the expressions (2.5-8) visually outline the main part of the theorem [3] cited above, at any rate for nonresonant conditions.

Let us consider the properties of media, in which the manifestation of superluminal phenomena can be possible at definite frequencies. Note here that in accord with (2.7), the frequencies domains of superluminal and subluminal, including so named “slow light”, are very close, it illustrates the experimental difficulties with searching of “superluminal ranges”.

As the instantaneous transferring is possible for virtual particles only, their formation length must be not lesser the free path length of photon \( \ell = 1/\rho \sigma \), where \( \rho \) is the density of scatterers (free and valent electrons), \( \sigma \) is the total cross-section of single \( \gamma \) process. The Thomp-son cross-section \( \sigma_{\gamma} \) presents the possibility of virtual particles only, their formation length must be not lesser the free path length of photons. Therefore the group index of refraction is given by the relation:
\[ n_g \equiv c/v_g = cT_1/L = 1 + cT_2/\ell \equiv 1 + c\rho_2 \tau_2 \sigma. \]  
(2.13)

If there are the superluminal (instantaneous) jumps on distance \( \Delta \ell \) at each scattering act, then \( N \to N\tau = L/(\ell + \Delta \ell) \) and correspondingly
\[ n_g \to n_g \tau = 1 + cT_1/(\ell + \Delta \ell) = 1 + (n_g - 1)(1 + \Delta \ell/\ell)^{-1}. \]  
(2.14)

In the region of anomalous dispersion, where \( v_g > c \), this definition can lead formally to \( n_g < 0 \).

Far from all resonances the scattering of low energy photons goes as the scattering on free electrons. Therefore, in accordance with the uncertainty principle, the delay duration can be estimated as \( \tau_n \approx 1/2\omega \) and since the group and phase indices of refraction are close, then such (rough) estimation for the free path length follows (2.13):
\[ \ell = cT_1/(n_g - 1) \approx c/2\omega(n - 1). \]  
(2.15)

Since the s-photon instantly jumps with each scattering act onto the length \( \Delta \ell \), the sum of pathes of this photon executing with the speed \( c \) would be equal to \( L_{eff} = L - N\Delta \ell \). Hence the ratio of photons mean velocity in transparent media to the light speed in vacuum can be estimated as
\[ u/c \approx 1 + \Delta \ell/\ell = 1 + 2\pi(n - 1). \]  
(2.16)

Just this expression must be comparing with experimental data. The most representative experimental data are considered in [3] that had shown the accordence of their results with the offered theory.

So for the light passage through the lightguide of sufficiently small radius, when light waves almost on all their pass has an evanescent character, the estimation (2.18) gives for typical values of refraction is given by the relation:
\[ L/c = \tau_n \alpha \approx 1 + \Delta \ell/\ell \approx 1 + 2\pi(n - 1). \]  
(2.16)

Note that this magnitude represents the maximal light speed in usually used materials and therefore its value should have an exclusive significance for optoelectronics, etc.

III. TEMPORAL FUNCTIONS OF MASSIVE PARTICLES INTERACTION

The temporal peculiarities of interactions of massive particles can be considered in the close analogy with procedures examined above. But now we must analyze the slightly more complicate Green functions \( \Delta_1(E, r) = \Delta_1 + i\Delta_1 \), where \( \Delta_1(E, r) = (1/2\pi)\sin(E^2 - m^2)^{1/2}r \) (here and below in this Section \( \hbar = c = 1 \)).

In the analogy with (2.6)
\[ \tau(E, r) = \frac{\partial}{\partial E} \ln \Delta_1(E, r) = \frac{iE}{(E^2 - m^2)^{1/2}} \cot(E^2 - m^2)^{1/2}r. \]  
(3.1)

and the relations with \( E > m \) and \( E < m \) must be separately considered
If \( E > m \), we have
\[ \tau_1 = 0, \]
\[ \tau_2 \to -\frac{m}{E^2 - m^2} - 2 \sum_{(E^2 - m^2)^{1/2}} \cot(E^2 - m^2)^{1/2}r. \]  
(3.2)
As in the contrast to QED an undressed static state is here absent, the main part of duration of particle (state) formation can be presented by the first term:
\[ \tau_2(E, r) \approx -E/(E^2 - m^2) \sim -1/2\Delta E, \quad (3.2') \]
which corresponds to the usually written form of energy-time uncertainty relation, but with negative sign. It means that the considered transition must be of advanced or instantaneous type, of tunneling character.

If \( E < m \), i.e. at consideration of coupled particles, then
\[ \tau_1 = \frac{E^2 - m^2}{(E^2 - m^2)^2} \coth(E^2 - m^2)^{1/2} \tau; \quad \tau_2 = 0. \quad (3.3) \]

Therefore it formally seems that in this case the possibilities of instantaneous transitions are absent. But if, as will be shown below, the product \( \tau(E, r)(E^2 - m^2)^{1/2} \) would be considered, it will become evident that for such case \( \tau_1 \) and \( \tau_2 \) must be interchanged, and the possibilities of instantaneous transitions still exist.

\[ (\mathbf{P}(t)) \geq \cos^2(\alpha t), \quad (4.7) \]

Here with some deflection from the initial consideration, related to the lifetime of excited or intermediate state, we can propose that the completion of transition means the return to the stable state after the definite time duration, and therefore the substitution of \( (\mathbf{P}(t)) \) at \( t = \tau \) in (4.6) leads to the condition (1.1):
\[ (\Delta H)_{\text{stable}} = \pi \hbar, \quad (4.8) \]
just corresponding to our results in the Section 2.

If \( E^2 - m^2 < 0 \) and \( \Delta H \) is pure imaginary, the magnitudes \( \tau_1 \) and \( \tau_2 \) are interchanged; the solution of relation (4.6) must be seeking in the form:
\[ \sin \alpha^2(\tau) \leq (\mathbf{P}(t)) \leq 1, \quad (4.9) \]
which culminates near to \( \alpha [\tau] \sim 1 \). It means the existence of uncertainty relation (1.3),
\[ (\Delta H)_{\text{virtual}} \sim \frac{1}{2} \hbar, \quad (4.10) \]
which formally coincides with the usual forms for such relations. The differences consist, of course, in possibilities of simultaneously pure imaginary values of both standard deviations.

It must be noted that the original result of [6] remains completely valid for the half time of decay state as (1.2).

Thus all examined types of processes must be considered separately. But as it must be underlined, the initial expressions (4.2) show that both standard deviations must have the same sign. Therefore it does not forbid the existence of negative \( \Delta \tau \) at negative \( \Delta H \) corresponding to the theorem, cited above.

Note that the restrictions connected with the Hermitian character of considered operators can be avoided by the most general formal deduction of uncertainty relations given by Schrödinger in [5]. The decomposition of the arbitrary operators’ product on the Hermitian and anti-Hermitian parts can be taken as
\[ AB = \frac{1}{2}(AB + BA) + \frac{1}{2}(AB - BA). \quad (4.11) \]

The subsequent quadrature of this expression, its averaging over complete system of \( \psi \)-functions and replacement for operators on difference of operators and their averaged values \( A \to A - \Delta A \), \( B \to B - \Delta B \) bring to such expression for standard deviations:
\[ (\Delta A)^2 (\Delta B)^2 \geq \frac{1}{4} [AB - BA]^2 + \frac{1}{4} [AB + BA] - 2 \langle A \rangle \langle B \rangle^2, \quad (4.12) \]
which differs from the more usual form by the last term and can strengthen the condition (4.2). The Heisenberg limit of this expression with \( [AB - BA]^2 \to h^2 \) and omitting of the second term shows a minimal value of uncertainties, which can be achieved for pure states, in the weakly correlated conditions. But this limit can be exceeded for some physical magnitudes (compare [4]), such possibilities are mentioned in other investigations also, e.g. [17]).

It must be noted that these relations can take place for the motion along one of coordinates only. So Wigner [18] specially underlined that these uncertainties depend on coordinates points, and if the process is progressing in the \( z \) direction:
\[ (\Delta t(z))^2 = \int dx dy dt (t - t_0)^2 |\psi(x, y, z, t)|^2 / \int dy dt |\psi(x, y, z, t)|^2, \]

IV. INDETERMINATENESS AND UNCERTAINTY RELATIONS, EVANESCENT PARTICLES

The establishments of precise expressions for energy-time uncertainties for different cases are crucial for our discussion. Therefore we must reconsider the deduction of these relations with demonstration of their differences.

The most simple case of deduction is such one. The probability of transition between states of one type with energies \( \bar{E} \) and \( E \) at perturbation of time is proportional to the expression (e.g. [16]):
\[ W \sim \Delta E^2 \sin^2 \Delta E \tau / 2\hbar, \quad (4.1) \]
Its maximum is determining as \( \Delta E \tau / 2\hbar = \pi / 2 + n\pi \), where both values can be negative in the complete correspondence with the condition (1.1). But such approach is restrained by specific conditions of scattering theory, and it could not be considered as the general rule for all interaction processes, including particles decay and their transmutations.

Let’s turn to the method offered by Mandelstam and Tamm [6]. They began with comparison of two quantum expressions for Hermitian operators \( A \) and \( H \), the Hamiltonian, with the standard deviations \( \Delta A \) and \( \Delta H \):
\[ \Delta H \cdot \Delta A = \langle [HA - AH] \rangle; \quad (4.2) \]
\[ \hbar \partial_i \langle A \rangle = i \langle [HA - AH] \rangle, \quad (4.2') \]
which leads together to the inequality
\[ \Delta H \cdot \Delta A \geq \frac{1}{2} \hbar \langle \partial_i \langle A \rangle \rangle. \quad (4.3) \]

For its analysis the projector of some definite state \( \psi_0 \) must be introduced:
\[ \mathbf{P} = \langle \psi_0, \psi \rangle \psi_0, \quad \mathbf{P}^2 = \mathbf{P}, \quad (\mathbf{P}) \leq 1, \quad (4.4) \]
its standard deviation is defined as
\[ \Delta P = \langle (\mathbf{P}^2 - (\mathbf{P})^2) \rangle^{1/2} = \langle (\mathbf{P}) - (\mathbf{P})^2 \rangle^{1/2}, \quad (4.5) \]
The substitution of (4.5) in (4.3) brings the main Mandelstam-Tamm relation:
\[ \Delta H \langle (\mathbf{P}) - (\mathbf{P})^2 \rangle^{1/2} \geq \frac{1}{2} \hbar \langle \partial_i \langle A \rangle \rangle, \quad (4.6) \]
satisfactory solution of which would be seeking in the form:
\[(\Delta E(z))^2 = \int dx dy dE (E - E_0)^2 |\psi(x, y, z, E)|^2 / \int dy dE |\psi(x, y, z, E)|^2, \quad (4.13)\]
and they can be different, in general case, for other space axes.

This peculiarity can be the starting point at investigation of the phenomena of frustrated total internal reflection (FTIR). In these phenomena the passing photons can propagate with subluminal speed along the waveguide axis, but the shifts in the perpendicular directions can be simultaneously instantaneous, and it can lead to the suitable interpretation of proper observations.

V. PARTICLE PHYSICS

Let's consider possibility of particles instantaneous tunneling into the state of higher mass; other characteristics can be transformed at such tunneling also and therefore it will lead to particles transmutation. Such processes can go with observance the energy-moment conservation, of course, i.e. at interaction with matter and must correspond to the condition (4.10) (here and below c = 1):

\[ (\Delta m \Delta \tau)_{\text{transmut}} \sim \frac{1}{2} \hbar, \quad (5.1) \]

where \( \Delta m = m_i - m_f < 0 \) and, correspondingly, \( \Delta \tau_{\text{transmut}} < 0 \). The processes of such transitions are experimentally discovered yet for neutral particles only. Therefore we begin with mesons and then will turn to the more uncertain processes with neutrinos.

First candidates to such transition are \( K^0 \) mesons. As \( m_{K_L} > m_{K_S} \), only the transition \( K_S \rightarrow K_L \) via the considered instantaneous transition seems possible. It is confirmed by the absence or by extremely rarity of \( K_S \) formation in the \( K^0 \) beam after definite distance, i.e. by impossibility or by the weakness of superweak interaction, usually attributable to the \( CP \) nonconservation. But we can consider such rare transitions as the opposite ones relative to the offered transmutations into higher mass states. The estimation of relative magnitudes of direct and opposite probabilities seems so far impossible.

Let's consider the experimental data for the "direct" process: \( m_{K_L} - m_{K_S} = 3.48 \cdot 10^{-12} \text{ MeV}, |\Delta \tau_{\text{int}}| \rightarrow \tau_{K_S} = 0.896 \cdot 10^{-10} \text{ s} \) [19] leads to the estimation:

\[ |m_{K_L} - m_{K_S}| \tau_{K_S} = 0.47 \text{ h}, \quad (5.2) \]
i.e. they almost completely conform (5.1).

For \( B^0 \) mesons the mass difference \( m_{B_{d}} - m_{B_{s}} = 3.3 \cdot 10^{-10} \text{ MeV} \) is known, but only the mean life time is determined: \( \tau = 1.55 \cdot 10^{-12} \text{ s} \). They give such estimation:

\[ |m_{B_{d}} - m_{B_{s}}| \tau = 0.775 \text{ h}, \quad (5.3) \]
but this value can be decreased if the life time of \( B^0 \) is lesser than of its partner.

For \( B^0 \) is determined only that corresponding \( \Delta m > 94.8 \cdot 10^{-10} \text{ MeV} \). It gives with (5.1) the estimation for the life time of \( L \)-partner: \( \tau_L < 5.5 \cdot 10^{-14} \text{ s} \).

The known uncertainty of \( D^0 \) parameters does not allow such estimations.

There are many other pairs of mesons, including charged ones, with such mass differences and times of decay, that can be considered as candidates into analogical transmutation processes, but it requires a special considerations far from our general aim. There is not seemingly any restrictions on analogical permutations among fermions also.

For neutrinos it can be assumed that their masses, if they exist, correspond to the commonly accepted hierarchy: \( m_{\nu_e} < m_{\nu_\mu} < m_{\nu_\tau} \) or to the three mass eigenstates \( m_1 < m_2 < m_3 \) not associated with particular lepton flavors (e.g. [20] and more recent reviews [21, 22]). Here we do not distinguish these possibilities.

It means, in accordance with our general assumption, the possibilities of only such instantaneous transmutations in matter to more massive partners:

\[ \nu_e \rightarrow \nu_\mu; \quad \nu_\mu \rightarrow \nu_\tau; \quad \nu_e \rightarrow \nu_\tau \quad (5.4) \]
and corresponding for antineutrino, but absence or suppression, at least, of the opposite transitions.

Such discrimination evidently contradicts to the \( CPT \) theorem. This uncleared discrepancy can be connected at the instantaneous transition with the violation of the Lorentz invariance needed for observance of this theorem (this point evidently requires further investigations).

The arguments for this critical situation is related the absence of observed transmutations of atmospheric \( \nu_\mu \)'s into \( \nu_e \)'s or sterile states. Indeed, \( \nu_\mu \rightarrow \nu_\tau \) transitions are also disfavored by the Super-Kamiokande data, which prefer the \( \nu_\mu \rightarrow \nu_\tau \) channel [22].

So in accordance with our hypothesis there is not neutrinos oscillations, but all their transmutations can be considered as the tunneling into states of higher mass. (The hypotheses of neutrino oscillations, which have in mind as the direct so the inverse transitions, were suggested independently in [23, 24].)

Note that the transmutations (5.4) with absence of opposite transitions can be considered as the inevitable processes of specific ordering, i.e. as the gradual phase transitions of neutrinos sets into possibly more passive states, but with bigger masses.

Let's consider as an example of application of the proposed theory the simplest and the most direct interpretation of the atmospheric neutrino transition into the \( \nu_\mu \) states [20]. It will give possibility for an independent estimation of the neutrino mass.

The angular distribution of contained events shows that, for \( E \sim 1 \text{ GeV} \), the deficit of \( \nu_e \)'s comes mainly from \( L \sim 10^2 \div 10^4 \text{ km} \). The corresponding oscillation (transition) phase must be maximal:

\[ \Delta m^2 (eV^2)L/2E(\text{GeV}) \sim 1, \quad (5.5) \]
which can be rewritten as

\[ \Delta m^2 (eV^2) \tau (\text{sec}) \sim 0.2 \cdot 10^{-11}. \]

The comparison with (5.1), rewritten as

\[ \Delta m (eV) \tau (\text{sec}) \sim 2 \cdot 0.10^{-15}, \]
leads to the estimation \( \Delta m \sim 10^{-4} \text{ eV} \), which does not seems qualitatively inconsistent.

Note that this estimation determines the upper bound on the scale of \( \Lambda \sim 10^{18} \text{ GeV} \), i.e. very close to the
Planck scale $M_{Pl} \sim 10^{19}$ GeV, and therefore it reduces the necessity for introduction a new fundamental scale or so named New Physics.

VI. CONCLUSIONS

Our examinations can be summed into such points.

1. The uncertainty or, more correctly, the indeterminateness principle must be considered for each type of interaction separately, and although the differences are only numerical, they can have different physical meaning.

2. Both standard deviations in the energy-time relations can be simultaneously negatively or even pure imaginary ones. The negativity of the time standard deviation can be interpreted as the instantaneous transition, the jump onto definite distance or as the tunneling through classically forbidden region.

3. The visible nonlocality in the small, i.e. the violation of Lorentz invariance can be considered on the same basis as the violation of conservation laws by virtual transitions, and it does not mean the violation of relativistic causality by these evanescent particles, in the whole process.

4. The revealed forms of uncertainty relations demonstrate the peculiarities of tunneling, and therefore they allow to explain and clarify the very old problems of negative duration of tunneling at the standard quantum calculations (e.g. [25]) as the natural feature of these transitions.

5. The new forms of uncertainties relations are deduced for transfer of some excitations and for transmutation of particles into their more massive partners. They allow some estimations and predictions of parameters of such transitions or transmutations.

6. All these results prove that the possibility of some evanescent violations of the classical Lorentz invariance are contained in the usual field theory and the introducing of them ad hoc is not needed.

7. The examined processes can be considered as the violation of the superselection rules ([26], in the modern form e.g. [27]), i.e. as the transitions between different sectors of the Hilbert space through the forbidden regions. They include the transitions between sectors with different parities types, flavors and so on. Therefore it can be presupposed that these transitions, completely or partly, are connected with violations of the Lorentz invariance and take place simultaneously with it or owing to it.

These considerations allow proposing some attractive hypotheses for further examinations.

The most stimulating among them seems the possibility of intimately connection of the Lorentz violation with violations of some discrete symmetries including $CP$ or even $CPT$ and conservation laws.

Another interesting perspective consists in the suggestion of processes (5.4) as the unique possible. They can lead, in particular, to the gradual transmutation of all neutrinos into $\nu_e$'s as the final state of all known neutrinos transmutations. If their mass is really bigger than of other neutrinos, then just the tau-neutrinos can become the primary candidates into the most part of a nonbarionic dark matter and essentially increase the neutrino contribution into the critical density of the universe (compare [20]).

On the other hand such possibilities of the instantaneous transfer of excitations in condensed states (macroscopic solids, atomic nucleus' and so on) must be investigated, as they can fulfill everywhere a definite role in the binding of constituents (cf. [28]).

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