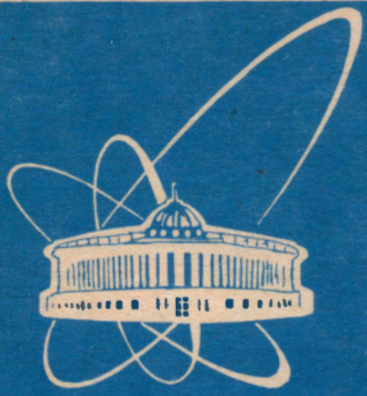

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TACHYONS — DIFFICULTIES AND HOPES

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Introduction

In formulae of Einsteinian theory of relativity the vacuum light velocity c occurs as an universal constant restricting permissible velocities of all signal transmissions. Since an approach of a velocity v of any material object to this value results in growing its mass $m = m_o\ (\ 1 - v^2/c^2)^{1/2}$ to infinity, for a long time one has taken as obvious that the region of superluminal velocities $v > c$ is unaccessible. However Ja.P.Terletsky [1 – 4] and thereupon M.Bilaniuk, V.Deshpande and E.Sudarshan [5] noticed that limitation could be removed if we assume that faster-than-light particles don't get over the light barrier but at once come into being with velocities $v > c$ and a (formally) imaginary mass $m = im_o$.

A great number of theoretical and even experimental investigations of various aspects of the "tachyon problem" have appeared. In the mid-80s a list of publications amounted already about thousand items /6/.

The results of these investigations were summarized in reviews [7–10]. The main conclusion is that a superluminal signal transmission results in an appearance of acausal anomalies when a cause and its effect switch the roles and time loops become possible with which one can influence on the past, i.e. on the already realized events. Due to this, as some authors see, a region of tachyon existence is limited to ultrasmall space intervals $\Delta x \leq 10^{-16}$ cm where T-invariance is violated and a strict time sequence of connected by an interaction events loses its universality. Other authors (see e.g. the encyclopedic E.Recami's review [10]) think that the difficulties can be avoided by means of a more extended interpretation of causation even at macroscopic scale. An opinion was expressed that the formation of acausal loops is only a for-fetched problem because due to peculiarities of superluminal particles their behaviour in our real Fridman-type Universe essentially differs from that what takes place in an abstract case of flat space-time, and tachyon is absorbed by vacuum every time before it has time to close some acausal loop.

At the same time it turned out that irrespective of the region of their existence tachyons are threatened by one more terrible danger. As sub- and superluminal bodies are absolutely equivalent from a kinematic point of view and there are no reasons to favor one over another, one may connect the reference frame which we used to describe what is going on with the either of these objects. It means that the Lorentz transformations has to be extended to faster-than-light motions where transitions occur from outer regions of the light-cone to its internal ones and backwards.

Only in this case our theory may be treated as completely relativistic invariant one. [1] Unfortunately, until recently all numerous attempts of superluminal generalization of Lorentz transformations resulted in contradictions.

Acausal effects and troubles connected with superluminal coordinate transformations are the main reason of the present drop in interest to the tachyon hypothesis. Below we shall discuss if it's possible to avoid the mentioned shortcomings.

Meanwhile, one cannot but take into account that tachyons appear in various string models, in theories with high-order lagrangians, by supersymmetric generalizations, and many physicists are of the opinion that this fact is not only a disappointing theoretical failing but a reflection of some reality and we did not learn yet how to use it properly.

And what is more, under some conditions (e.g. for orbital motion in black hole gravitation field) even in the Einsteinian theory velocities of particles (photons,neutrino) could be larger than the vacuum light velocity c [11,12]. [2]

The gould of our paper is to analyse the state of the tachyon hypothesis as it looks at present — ten years after the last reviews in this region [9,10].

The investigation of properties of the hypothetical faster-than-light particles ,even if they will not be discovered in experiments, is of great interest as a study of one of possible extensions of the theory of relativity — as a theoretical reconnaissance in the region of quite unknown space-time relations.

[1]The mentioned difficulty is present in any theory with non-local interaction. For example, in a field theory with form-factor where space- and time-like points get into the interaction term $\int \phi(x_1)\phi(x_2)A(x_3)d^4x_1x_2x_3$ quite equivalently the reference frames tied to these points can be both types —a sub- and a superluminal one .A formal relativistic invariant form of equations by himself doesn't yet provide the complete Lorentz invariance of the theory.

[2]This paradoxical, impossible at first sight phenomenon is due to a virtual particle dissociation ($\gamma \to e^+ + e^-$) when the particle acquires a dimension $\sim \lambda = \hbar/m_e c$ and a tidal effects of an anisotropic gravitation field, as calculations have shown, increase or decrease its velocity in comparison with the vacuum one. True, the calculations are still rather rough and one cannot exclude that "superluminal light" is only a virtual quantum effect.

If is it possible to avoid causality violations?

The violations result from the properties of the relativistic space-time transformations. If a signal linking events in points (x_1,t_1) and (x_2,t_2) is transmitted with the speed

$$v = (x_2 - x_1)/(t_2 - t_1) \equiv \Delta x/\Delta t > c,$$

then in a moving with speed u reference frame (u may be a *usual* subluminal velocity) the time interval

$$\Delta t' = (\Delta t - \Delta x u/c^2)\gamma = \Delta t(1 - uv/c^2)\gamma < 0,$$

where $\gamma = (1 - u^2/c^2)^{1/2}$. In other words, the time order of linked by a tachyon signal events depends on the used reference frame and by a choice of the velocity u may be do always so that the event-effect will forestall the respective event-cause. By an increasing of the observer's speed u the tachyon part of a considered process drops out at first of his field of vision, then by $uv = c^2$ it becomes instantaneous and by $uv > c^2$ swings backward in time.

True, by himself such unusual evolution of events doesn't yet mean that causality is violated since simultaneously the tachyon energy changes its sign too:

$$E' = (E - pu)\gamma = E(1 - uv/c^2)\gamma < 0,$$

thanks to which the interaction process may be treated as a motion of an antitachyon from the point (x_2,t_2) to the point (x_1,t_1). Such an interpretation (one names it as a reinterpretation principle [3] means that the conventional formulation of causation according to which any event-cause has to remain as such under all possible conditions is replaced by more "soft" ones when only the fact of an interaction transfer [4] between two

[3]In paper [13] an approach was developed by which the tachyon energy sign is determined depending on if the considered particle is created or absorbed. That allows to manage only with positive tachyon energies and don't use the reinterpretation principle. However such an alteration of tachyon theory does not tell about a discussion of the causality problem.

[4]Let us remember that in contrast to all other relationships, the causation is just characterized by an information transfer, i.e. as philosophers say, it is a profound *genetic* relationship. Some times causation is defined as that which is sure to be accompanied by a momentum-energy transition. However the definition with using the notion of information is more general because there are situations (e.g. in the Einsteinian gravitation theory) when momentum and energy lose any sense [14].

events is considered as an absolute one, independent of a reference frame choice whereas an identification of these events as a creating (cause) and a created (effect) makes relative,conventional sense just as the meaning of a simultaneity in the present theory of relativity. Within the limits of T-invariant microscopic theories such an extension of causation doesn't provoke any troubles but acausal effects appear at once when one passes to a real macroscopic situation with the strictly fixed time-arrow which is quite independent of the reinterpretation principle.

Let us remember the example adduced in our review [9]. A source and a detector of tachyons are separated by a screen modulating the tachyon beam intensity according to a strictly definite code. If within some reference frame the action of the modulator precedes a signal of the detector, then in another frame moving with respect to the first one this detector himself turns into a spontaneously-coded antitachyon source the variation of which are smoothed by the screen-modulator. In this beam, for instance, a Shakespeare's sonnet or the USA Constitution my be coded by means of Moorse alphabet and a moving observer will apprehend an inexplicable acausal event. The macroscopic source and detector are not T-invariant, the reinterpretation principle is not applicable to them. By himself, the fact of a transformation of a quite unadapted for that detector into a tachyon generator looks like a genuine wonder. Producing a tachyon beam the source spent an energy but the detector is not provided by any energy for tachyon generation. It turns out that practically every object can be used as a high-capacity generator of faster-than-light particles.

One can avoid the difficulties by means of one of two ways — to eliminate tachyon velocities $v > c^2/u$ or to attempt to extent the present treating of causation so that the cause-effect exchange in macroscopic processes could be considered just as an illusion and every time we could determine precisely the primary, initiating event. [5]

[5]Generally speaking, there is a third way — to abandon the relativistic invariance, particularly the known now Lorentz transformations. One can see review on such attempts connected with the tachyon problem in the papers [10, 15]. Nevertheless, such an approach seems to be little perspective. If the abandon the relativistic invariance concerns both super- and subluminal particles just contradictions with experiment spring up because at present there are no reliable evidences of relativity principle violation [16]. On the another hand, if one assumes the relativity violations for faster-than-light objects only, a problem arises how to justify this hypothesis. We have no forcible arguments for that now.

The first approach was considered by E.Recami with his collaborators [19 – 22] and by V.Perepelitsa [23 – 25]. In Recami's papers it was shown that the condition $v < c^2/u$ is provided automatically by the energy- momentum conservation law if speed and mass of tachyon, its source and detector satisfies some kinematic relation. In all other cases the tachyon is not absorbed by the detector — the latter just doesn't take notice of him. At the same time the prohibition to absorb the tachyon by the detector as a whole doesn't forbid an absorption of this tachyon by a part of the detector. Besides, the absorption is not the only type of tachyon interactions. A tachyon elastic scattering may also be used to detect it and in this way one can get acausal effects as well.

Some authors noticed (see e.g. [26]) that a behavior of faster- than-light particles must be essentially dependent on the Fridman space-time "swelling" and as V.Perepelitsa noticed this fact is important for the discussion of the causality problem. The taking into account of the Fridman space-time metric results in a prohibition of tachyon velocities $v > c^2/u$ where u is a velocity of the observer's reference frame with respect to the so called accompanying reference frame defined by the condition of a Fridman swelling isotropy. One can show that the oscillating superluminal particle wave function turns into an exponentially damping one what could be interpreted as a "dissolution" of the considered tachyon in vacuum [25].

We shall not dwell on proofs of those assertions since that way, all the some. only a part of the mentioned above difficulties could be removed. Indeed, as in the accompanying frame any tachyon velocities $0 \leq v < \infty$ are possible (the boundary value $v_{max} = c^2/u \to \infty$ by $u \to 0$) in other reference frames moving with speeds $v > c^2/u$ cause and effect switch the roles. Nevertheless, from our moving frame one cannot now send a signal

In the mentioned above case of photon superluminal velocities in Einsteinian gravitation theory an extended photon feels a local space-time curvature, therefore its motion isn't inertial, simple Lorentz transformations are not applicable and, respectively, the conclusion about unavoidable acausal anomalies becomes wrong.

There are some theoretical considerations to wait for a relativistic invariance violation in a region of Plank's intervals $\Delta x \sim 10^{-32} cm$ and at a level of superhuge distances bearing traces of primordial cosmic phenomena (see e.g. [7, 18]). One may also wait for a violation of the Lorentz transformations in a very narrow interval near by light barrier $v \simeq c$ where modern theory results in physically meaningless divergent quantities. However, all these space-time and energy regions are yet far more than limits of our experimental possibilities.

whose velocity $v > c^2/u$ and which could have an influence on bygone events in the accompanying frame (see Fig.2).

So, the Fridman space-time expansion prevents the formation of any acausal loop. In other words, one cannot send a tachyon message to the past and change the already formed order of events (one can not "kill oneself in a cradle" or receive some information about our destiny from an living in the future observer). It is true not only for the accompanying but for any other reference frame as well, because in transition between any two reference frames one can use the accompanying one as a "way-station" , and this fact secures against time loops. Unfortunately, against a background of cause-effect transpositions these conclusions resemble a medical diagnosis ascertaining that " before death the patient has perspired what is, undoubtedly, a optimistic symptom"...

Though, if one may contend with certainty that the time non-invariance of cause-effect chains of events is indeed a defect of theory? May be, it is just a matter of habit stipulated by a scantiness of our experience? For instance, in Peripelitsa's opinion "causation as a logical principle is only a demand of an independence of causes on their effects, and that is all. The principle says nothing about any cause-effect time order. One demands only a lack of time loops" [25].

Such an extension of the generally accepted causality principle is quite permissible with respect to microprocesses [14, 27] but in the considered above example with a modulating screen it does not matter what forces the screen to rattle off a Shakespeare's sonnet — some beforehand compiled code or a spontaneous radiation of our receiver which suddenly turns into a transmitter. Independently whichever logical reasonings are produced as an justification, these two situations are evidently incompatible and we have to admit that one of them is just not realized.

In another typical example, a soldier shots at a mine which explodes and its splinters fly away. A moving observer sees that some originally motionless pieces fly up spontaneously and become one. The formed object emits a bullet which in one's turn *knows* a soldier rifle direction and flies exactly in its barrel.

The second law of thermodynamic forbids such phenomena. The macroscopic time irreversibility is a good proved fact [14].

True, some time even under usual conditions when we only deal with subluminal speeds one cannot distinguish effect and cause without an additional information. For example, an observer fixing a light and sound

signals (see Fig.3) often is unable to decide which of them is a cause — did the sound call forth the observed light flash or, on the contrary, this light flash gave rise to the fixed sound signal. To settle a question one has to perform an additional investigation, i.e. to investigate the ways of these signals, their velocities and so on. Similarly, taking into account the accompanying events (i.e. investigating the forehand history), one can always get to know which of two connected by tachyon events is the veritable cause. [6] However, the cases with sub- and superluminal signals differ principally: while any sequence of light and sound signals doesn't violate the principle of macroscopic time-irreversibility and is not accompanied by paradoxical phenomena, a spontaneous emiting of coded tachyon beams by means of absolutely unadapted for that objects looks from any viewpoint as a wonder. The "events from nowhere" have not take place in any reference frame independent of the type of its connection with others coordinate systems. Acausal paradoxes could be removed if we abstract ourselves from macroscopic environment where the invariant time-arrow has the ball. In particular, it has been demonstrated once again in the last Recami's report [28]. However, in the case of macroscopic processes the acausal phenomena produced by superluminal signals are unavoidable.

There is one more objection against the principle of extended causation. This principle doesn't explain why the phenomenon of an influence of the future on the present and the past occurs only inside a selected class of events (with tachyons) but doesn't become apparent for other cases where, generally speaking, it could take place too. Essentially, it is one more hypothesis.

So,the conclusion that faster-than-light particles if they indeed exist in Nature can appear only at a level of ultrasmall space-time intervals [7, 9] remains valid. In this case the tachyon hypothesis coincides, in fact, with an investigated by many authors conception of non-local interaction and may be considered as its corpuscular realization. The causality demand is equivalent to an integrability condition of non-local equations of

[6] In this case we have to reconcile ourselves to a relativity principle violation because one can always learn which of two inertial reference frames is at rest and which is the moving one. We have to consider as being at rest that frame where there are no paradoxical phenomena and cause precedes its effect. The relativity principle is conserved in microscopic processes where elementary particles interact equally with tachyons and antitachyons; under these conditions it does not matter which of two events is considered as a cause.

motion [14] and is satisfied only at ultrasmall values of $\Delta x, \Delta t$.

Superluminal Lorentz transformations

In the case of two-dimensional space-time world which as the simplest example is considered in many tachyon investigations there is an elegant extension of the subluminal Lorentz transformations over the region of faster-than-light velocities $v > c$ [15, 29]:

$$\left.\begin{array}{l} x' = \varepsilon\gamma(x - vt) \\ t' = \varepsilon\gamma(t - vx/c^2) \end{array}\right\}, \qquad (1)$$

where $\gamma = (|1 - v^2/c^2|)^{-1/2}$; $\varepsilon = 1$, if $|v| < c$, and $\varepsilon = -v/|v|$ if $|v| > c$. It is easy to show that these transformations form a group; [7] the regions of sub- and superluminal phenomena are completely symmetric. Depending on the reference frame where a particle is considered the last could be a tachyon or an usual subluminal body. (Particularly, from the viewpoint of an "tachyon observer" moving with a speed $v > c$ we ourselves and all surrounding us matter are made of tachyons). With respect to objects possessing different speeds the reference frame becomes apparent as a sub- or a superluminal one as well. [8]

Space and time co-ordinates x and t are also symmetric objects with respect to the light barrier: by a transition to superluminal frame they switch the roles,i.e. x' becomes equivalent of a time coordinate but t' plays a role of space coordinate. It's easy to be convinced of that by the change $v \to c^2/w$ in formulae (1). Then

$$\left.\begin{array}{l} t'c = \varepsilon_w\gamma_w(x - tv) \\ x'/c = \varepsilon_w\gamma_w(t - xw/c^2) \end{array}\right\}, \qquad (2)$$

where $\gamma_w = (1 - w^2/c^2)^{-1/2}, \varepsilon_w = -\varepsilon$, the velocity w is a subluminal one, and comparing to (1) we see that the quantities $(t'c)$ and (x'/c) are, in fact, respectively, new space and time coordinates.

[7] It's interesting to note that two successive transformations with velocities $v_i > c$ are equivalent to the Lorentz transformations with the *subluminal* velocity $V = (v_1 + v_2)/(1 + v_1v_2/c^2) < c$. In the boundary case when $v_i \to c$ the velocity $V \to c$ also. When $v_i \to \infty$ the summary velocity $V \to 0$.

[8] In recent paper [30] the question is discussed in details from a purely geometrical point of view and a transition to a new reference frame is treated as a rotation in the complex Minkowski space

The switch the roles of space-time coordinates becomes especially evident when $v \to \infty, w \to 0$. In this case the relations (2) look as

$$x' = ct, t'c = x \qquad (3)$$

(see Fig.4). [9] For example, whereas in the laboratory coordinate system a meson is created and absorbed being at the same point x, in a reference frame moving with infinity speed its history looks as its *simultaneous* creation, existence and decay at different distances in a line. In other words, particle lifetime contracts up to a infinity small value (becomes instantaneous) and particle "age alterations" assume the meaning of purely space characteristics. If in the laboratory frame our meson is moving, then a superluminal observer interprets its displacement as a meson lifetime increasing, i.e. just in the same manner as we take our time. A similar thing occurs by an interception of the black-hole Schwarzschild radius,where space and time switch the role too.

One would think that the transition to the case of four-dimensional space-time doesn't give rise to any difficulties — we must only supplement the formulae (1) with two relations:

$$y' = y, z' = z. \qquad (4)$$

Indeed, the transformations (1), (4) form a group, however, in this case light velocity stops to be a constant universal quantity but becomes dependent on the concrete choice of reference frame and on a direction of light-wave motion. If in an initial frame a light flash is taken by an observer as an expanding in time spherical surface $x^2 + y^2 + z^2 = c^2t^2$, then in a superluminal frame it looks as two in a moment flashed and flying one from another hyperboloids $x'^2 - y'^2 - z'^2 = c^2t'^2$ with in like manner shining near and distant points (see Fig.5). The light velocity on the spherical surfaces

$$c(x', y', z') = [c^2 + 2(y'^2 + z'^2)/t'^2]^{1/2},$$

[9] The presence of the sign function ε in the extended Lorentz transformations is stipulated by the transposition of x' and t'. In the case of transformations with $|v| < c$ an unbroken transition from positive values v to negative ones is possible, but when $| v |> c$ such transition occurs by leap,so one may choose one of two possible coordinate axis directions of the moving reference frame: $x \to t', t \to x'$ or $x \to -t', \to -x'$ (see Fig.4). The sign function $\varepsilon(v)$ corresponds to the first possibility providing a perfect symmetry of sub- and superluminal reference frames. Besides, if the function $\varepsilon(v)$ isn't introduced then, as it was shown in the paper [27], the extended Lorentz transformations (2) doesn't form any group: $L(v_2)L(v_1) \neq L(v_2 \oplus v_1)$.

and the squared fore-dimensional space-time interval defining the light-wave front

$$s^2 = x'_\mu x'^\mu \neq x_\mu x^\mu.$$

Clearly, by such conditions the relativity principle is violated because observing the shape of a light front one can arrive at quite definite conclusion about the observer's velocity.

And what is more, one can show [29,31] that a successive use of several four-dimensional sub- and superluminal Lorentz transformations (1), (4) is equivalent to a group of linear four-dimensional transformation $x'_\mu = \Lambda(v)_{\mu\nu}x^\nu$ with only one restriction $Det\Lambda = \pm 1$. The demand of the Lorentz invariance results in this case in some experimentally non-observable symmetries. It's easy to check that considering, for example, an operator $L_{ty}\Lambda(v)L_{ty}$ where L_{ta} is the transformations (1), (4) with the co-ordinate substitution $x \to a, \Lambda(v)$ is precisely the Lorentz boost (1), (2). The result of the considering transformation

$$\left.\begin{array}{c} x' = \gamma(x - vy) \\ y' = \gamma(y - vx) \\ z' = z, t' = t \end{array}\right\},$$

is equivalent to the rotation on the angle $\phi = -\arctan v$ in a plane (X, Y) and to a $\gamma(1 + v^2/c^2)^{1/2}$-times dilation of the axes X, Y.

One more obvious case is the transformation $L_{tx}R_zL_{tx}L_{ty}$ where R_z is a rotation on the angle $\pi/2$ around the axis Z.The result is the time inversion

$$t' = -t, \mathbf{x}' = \mathbf{x}$$

in respect to which Nature phenomena are far from being always invariant.

How one may improve the situation?

Several authors (see review [10]) attempted to get out of the difficulties by means of a transition from the usual real co-ordinates to the complex ones replacing the relations (4) by

$$y' = iy, z' = iz. \qquad (5)$$

In this case the imaginary unit square i^2 compensates the sign change of the quantities y'^2 and z'^2, so the squared four-dimensional interval conserves its absolute value:

$$s^2 = x_\mu x^\mu = -x'_\mu x'^\mu.$$

Unfortunately, as in the case of purely real coordinates , the result of several successive transformations (1), (5) is again a linear ("non-Lorenzian") transformation which corresponds to experimentally non-observable symmetries [15]. Furthermore, side by side with imaginary quantities iy and iz there appear automatically imaginary values of all other space-time coordinates $X_\mu = X'_\mu + iX''_\mu$ as well, and not only in a superluminal region but for $|v| < c$ too.

The general case of the coordinate transformations in the four-dimensional complex space-time has been considered by E.Cole [32]:

$$\left.\begin{array}{c} X' = \varepsilon\gamma(X - vT) \\ T' = \varepsilon\gamma(T - vX/c^2) \\ Y' = \nu Y, Z' = \nu Z \end{array}\right\}, \qquad (6)$$

Here the function $\nu = 1$ if $|v| < c$ and $\nu = i\varepsilon$ for $|v| > c$. Such an approach conserves the squared space-time interval s^2 however, it doesn't remove the difficulty with supplementary non-obervable symmetries appearing as a result of several successive transformations (6). [10]

Besides, a physical interpretation of complex co-ordinates remains unclear. In the region $|v| < c$ the quantities ReX_μ and ImX_μ are not connected, i.e. the real and imaginary "halfs" of the world exist quite independently and in the both "half-worlds" a light-wave surface is spherical:

$$ReX_\mu ReX^\mu = ImX_\mu ImX^\mu.$$

The case is somewhat different in the region $|v| > c$ where a transition to a superluminal reference frame confuses both real and imaginary co-ordinates and the front of a "real" spherical light-wave $ReX_\mu ReX^\mu$ is distorted depending on supplementary variable values. The particle velocity if it's defined by the usual relation $u^2 = (dx_k/dt)(dx^k/dt)$ where $k \leq 3$ turns out also to be dependent on these variables. [11]

[10]The demand of a conservation of the quantity s^2 is insufficient to select only the relativistic invariance. The square s^2 remains constant by all transformations $X' = \Lambda X$ which satisfy the condition $\Lambda^T G\Lambda = \pm G$ where the metric matrix $G_{11} = -1, G_{\mu\mu} = 1$ for $\mu > 1$ and $G_{\mu\nu} = 0$ by $\mu \neq \nu$. Particularly, transformations connecting points of two co-ordinate systems with zero relative speed are among such transformations too. Combinations of such a "static transformation" with "dynamical" ones (1), (5) cannot be represented by a Lorentz boost [13].

[11]In papers [33,34] one has proposed to use the complex co-ordinates for description of extended objects characterizing the center point and the length of such an object,

The difficulties of an superluminal extension of the Lorentz transformations were, perhaps, the main reason for the loss of an interest to the tachyon hypothesis. It is important ,meantime, to emphasize that these difficulties concern not only theories of classical tachyon particles but also all non-local extensions of modern theory. At the same time a disregard of the sub- and superluminal reference frame symmetry would be highly undesirable because the demand of the relativistic invariance is now one a few heuristic principle "illuminating the way" for non-local generalizations. [12]

Nevertheless, the situation is not, probably, so hopeless as someone assumes usually to think. There are reasons to suppose that the difficulties are not due to peculiarities of tachyon itself but are stipulated by shortcomings of the considered transformations. Really, the last ones have to do with the case of non-parallel moving coordinate axis X and X' but, as it was yet above mentioned, in the superluminal region actually a transposition of space and time axes occurs and the transformed events take place *in another light-cone* of four-dimensional space-time (see Fig.6). That breaks the initial condition of a axes parallelism. In this case we have to do, in fact, not with a transformation of co-ordinate systems when *the same* event is considered from two different viewpoints but with a purely mathematical operation determining a correspondence (mapping) of *distinct* points placed inside and outside the light cone. (This circumstance was noted in paper [36] also).

One can satisfy the condition of a parallelism of initial and final co-ordinate axes if the quantities $(t'c)$ and (x'/c) are treated in a superluminal reference frame, accordingly, as a space co-ordinate and a time moment. Just so they are interpreted by a superluminal observer. In

respectively, be real and imaginary components of X_μ. Indeed, in a world where by means of superluminal velocities one can instantaneously displace from one end of an extended body to the other notion of a point object becomes some anachronism. Up to now, however, nobody managed to remove in this way the difficulties connected with the particle velocity definition and with a light-wave front distortions in vacuum.

[12]Some authors (see e.g. papers [35, 36], a more earlier results are cited in the review [10]) proposed to take into account the relativistic symmetry *only* in the case of subluminal phenomena while in a superluminal region to consider as possible relativity principle voiolations and, respectively, the existence of a privileged reference frame. However, such an approach doesn't get ancouragement.

this case the transformations (1),(2) can be combined:

$$\left.\begin{aligned} x' &= \gamma(x - tu) \\ t' &= \gamma(t - xu/c^2) \end{aligned}\right\}, \qquad (7)$$

for $\gamma = (1 - u^2/c^2)^{1/2}; u = v$ if $|v| < c$ and $u = c^2/v$ for $|v| > c$. The function ε is unnecessary now since transitions from negative to positive velocities u occur uninterruptedly (see the footnote 9).

It's easy to check that the transformations (7), as the former ones (1), form a group. The velocity addition law takes now the form

$$U = (u_1 + u_2)/(1 + u_1u_2/c^2).$$

The quantity U is interpreted here depending on the coordinate system in which the transformed event (x'', t'') is considered. If it is a subluminal one (i.e. two subluminal or two faster-than-light velocities are added), then the right part of expression (8) equals

$$(v_1 + v_2)/(1 + v_1v_2/c^2).$$

In this case $U = V$, i.e. it is the summary speed. However, if the event (x'', t'') is observed in a faster-than-light reference frame (i.e. a sub- and a superluminal velocities are added), then

$$U = (1 + v_1v_2/c^2)/(v_1 + v_2) = 1/V.$$

As the transformations (7) conserve not only the value but also the sign of two-dimensional interval $x^2 - c^2t^2$, we get the four-dimension Lorentz transformations, if the relations (7) are supplemented by the equalities (4).

So, the demand of the relativistic invariance doesn't forbid an existence of tachyons. The interdiction (in any case at macroscopic level) results from physical and methodological considerations which have no direct reference to the theory of relativity. In this connection it would be extremely interesting to show some microscopic phenomena experimental investigation of which could be used for sufficiently convincing check-up of tachyon hypotheses since up to now all attempts to discover some traces of faster-than-light processes had to do with macroscopic space-time or could be treated nonsynonymously.

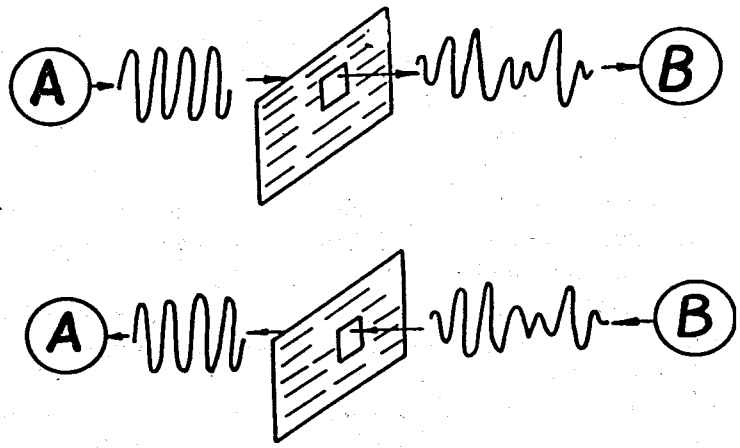

Fig.1. Modulation of a tachyon beam. Within reference frame 1 (an observer is at rest) the beam is modulated when it passes the screen aperture. Within reference frame 2 (the case of a moving observer) the modulation happens when particle beam doesn't yet reach the screen.

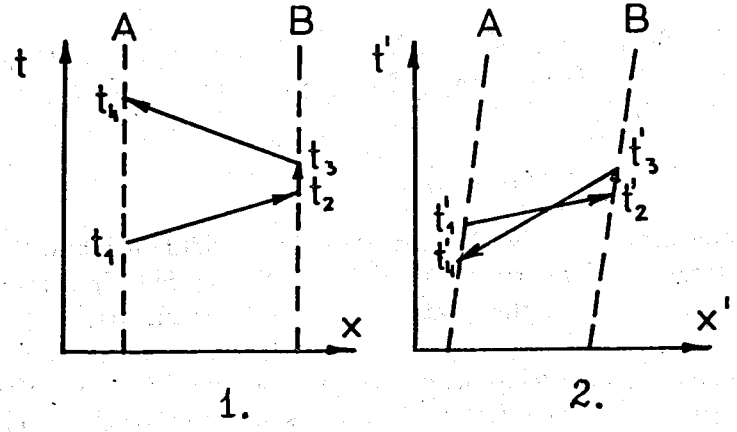

Fig.2. Time loop formed by two tachyon signal exchange. The cases 1 and 2 concerns, respectively, a motionless and a moving reference frame. The lines A and B are trajectories of two tachyon sources. In the moving frame the processes of tachyon emitting and absorption occur in a reverse order. In expanding Universe one cannot send a tachyon signal from t'_3 to t'_4 so that the moment t'_4 precedes the moment t'_1, i.e. the time loop is always not closed.

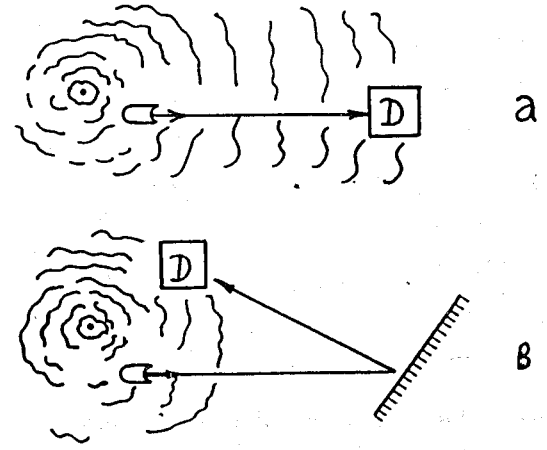

Fig.3. A light flash and a siren sound signal are fixed by a detector D. In the case a the both signals were sent in the same direction. Then independently on which is the cause (the sound impulse has switched the light or, on the contrary, the light signal has set going the siren) the light is detected before the sound.
In the case b the light and sound signal ways are differ in length. Than for some ways the sound would be detected as a first.

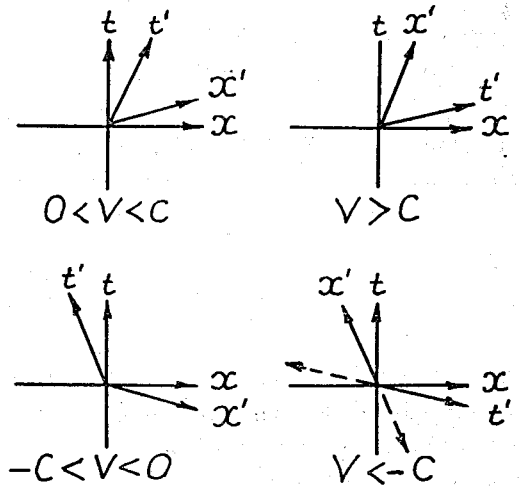

Fig.4. The arrangement of coordinate axes of a motionless (x, t) and a moving (x', t') reference frame when its velocity v is sub- or superluminal. The dotted line corresponds to the function $\varepsilon(v) = 1$.

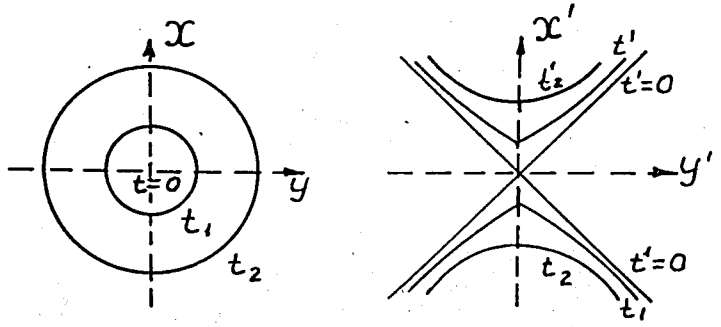

Fig.5. Light wave surface when seen at various times from a laboratory (x, y, t) and a superluminal (x', y', t') reference frames. For simplicity of the picture the z-axis is omitted.

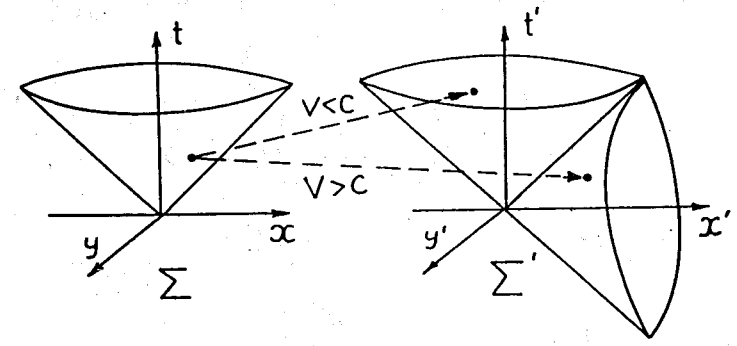

Fig.6. Transitions to a reference frame Σ' moving with a speed $|v| < c$ retain space-time points inside the same light-cone as it was in the initial frame Σ. Transitions to a superluminal reference frame Σ' transform they into another region of four-dimensional space.

Conclusion

As we see, the Einsteinian relativistic theory basic postulate saying that vacuum light velocity c is the highest possible in Nature speed is very stable. The supposition about an macroscopic existence of faster-than-light particles results in unavoidable contradictions; can such particles create in the region of an ultrasmall space-time intervals it's, first of all, the question to an experiment. Now any theoretical restrictions are not known for that.

In N. Bishop's paper [38] it was shown that a tachyon particle gravitation field can bend trajectories of surrounding bodies constituent parts which owing to that decay and are razed. One could think that it is a forcible argument again the tachyon hypothesis because up to now anything like that has been observed. However, this conclusion was derived in a classical approximation while at a level of ultrasmaal scales where one could expect a tachyon particles appearance we have to take into account a quantum spreading of the trajectories but an influence of this effect has not been investigated up yet.

As before, the question of the existence of faster-than-light particles remains open. Of course, it's very seldom managed to close a physical hypothesis "up to end", nevertheless, in many scientist's opinion the contraction of the region of possible tachyon existence up to an ultrasmall sizes and a lack of any experimental evidences of such particles (and, generally, any non-local phenomena) are quite enough to forget about the tachyons. At the same time one cannot except that such a conclusion is premature because, as it was mentioned above, the superluminal particles appear surprisingly in various generalizations of modern theory. It's hard to believe that it is an accidental circumstance.

References

1. Terletsky Ja.P. Doklady Akad. Nauk SSSR.1960,v.133,p.329.
2. Terletsky Ja.P. Phys. et Radium.1960,v.21,p.681.
3. Terletsky Ja.P. Phys.et radium.1962,v.23,p.910.
4. Terletsky Ja.P. Paradoxes of Theory of Relativity.Moscow,Nauka,1968.
5. Bilaniuk M.P.,Deshpande V.K.,Sudarshan E.C.G. Amer.J.Phys.1962, v.30,p.718.
6. Perepelitsa V.F. In book "Philisophical Problems of the Hypotesis of Faster-than-light Particles".Moscow,Nauka,1986,p.151.

7. Barashenkov V.S. Uspechi Fiz.Nauk.1974,v.114,p.133.
8. Recami E.,Mignami R. Riv.Nuovo Cim.1974,v.4,p.209.
9. Barashenkov V.S. In book "Philosophical Problems of the Hypotesis of Faster-than-light Particles".Moscow,Nauka,1986,p.5.
10. Recami E. Riv.Nuovo Cim.1986,v.9,p.1.
11. Drummond I.T.,Hathrell S.J. Phys.Rev.1980,v.D22,p.343.
12. Daniels R.D.,Shore G.M. Nucl.Phys.1994,v.B425,p.634.
13. Schwarz C. Phys.Rev.1982,v.D25,p.356.
14. Barashenkov V.S. Problemes of Subatomic Space and Time.Moscow, Atomizdat,1979.
15. Marchildon L.,Antipa A.E.,Everett A.E. Phys.Rev.1983,v.D8,p.1740.
16. Barashenkov V.S.,Yur'ev M.Z. Commun.JINR E2-94-21,Dubna,1994.
17. Niclsen H.B.,Picek N.P. Nucl.Phys.1983,v.B211,p.269.
18. Gasperini M. Phys.Rev.Lett.1985,v.B163,p.84.
19. Pavŝiĉ M.,Recami E.,Ziino G. Lett.Nuovo Cim.1976,v.17,p.257.
20. Pavŝiĉ M.,Recami E. Nuovo Cim.1976,v.A36,p.171.
21. Pavŝiĉ M.,Recami E. Lett.Nuovo Cim.1977,v.18,p.134.
22. Recami E. Lett.Nuovo Cim.1978,v.21,p.208.
23. Perepelitsa V.F. Prepr. ITEP-156,Moscow,ITEP,1976.
24. Perepelitsa V.F. Prepr. ITEP-121,Moscow,ITEP,1978.
25. Perepelitsa V.F. In book "Philosophical Problems of the Hypotesis of Faster-than-light Particles.Moscow,Nauka,1986,p.40.
26. Norlikar J.V.,Sudarshan E.C.G. Month. Notice Roy.Astron.Soc.1976, v.175,p.105
27. Blokhintsev D.I. Space and Time of Micro-World.Moscow, Nauka,1970.
28. Recami E. INEN/FM-94/02.Rep.of Inst.Nazion. Fiz.Nucleare, Milano,1994.
29. Marcildon L.,Antipa A.F.,Everett E. Can.J.Phys.1983,v.61,p.256.
30. Teleghko G.M. Ukr.Fiz.Ghorn.1993,v.38,p.183.
31. Gorini Y. Commun.Math.Phys.1971,v.38,p.150.
32. Cole E.A.B. Nuovo Cim.1977,v.A40,p.171.
33. Kalnay A.J.,Toledo A.J. Nuovo Cim.1977,v.48,p.997.
34. Kallnay A.J. Nuovo Cim.1980.v.27,p.437.
35. Bishop N.T. Found Phys.1984,v.14,p.133.
36. Bishop N.T. Found.Phys.1988,v.18,p.571.
37. Kovalczynsky J.K. J.Theor.Phys.1984,v.23,p.27.
38. Bishop N.T. Found.Phys.1989,v.19,p.619.

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