BEYOND THE VELOCITY OF LIGHT?

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Since the special theory of relativity introduced the velocity of light in vacuo as an invariant, superluminal phenomena for a long period were not discussed. One can argue that faster-than-light signals contradict the fundametal idea of special relativity. These signals might be used for clock synchronization and in the limit of infinite velocities absolute time would be reestablished and the Lorentz transformation replaced by the Galilei transformation.

Let us explicitly allege an old argument against superluminal signals. Suppose in an inertial frame of reference S the first event (ct,x) as the cause, e.g. emission of the signal, and the second event (cT,X) as its effect, e.g. detection of that signal. For a signal transmitted faster than light: $(X - x)/(cT - ct) = V/c>1$. In another inertial frame of reference S' moving with velocity v along the common x and x' axes, the Lorentz transformation gives for the time interval between both events: $cT' - ct' = \gamma(1-vV/c^2)(cT-ct)$. If the relative velocity of the systems $v>c^2/V$ (and $v<c$), the time sequence of the events is changed. If the time sequence should not be changed, the limitation $V \leq c$ must be valid.

In 1962, however, Bilaniuk, Deshpande, and Sudarshan proposed a way to circumvent this argument.[1] They introduced faster-than-light particles, known as tachyons, that can have positive total energy only and can travel only forwards in time. By means of the reinterpretation principle a tachyon with negative energy travelling backwards in time is interpreted as an antitachyon with positive energy travelling forwards in time. As total energy is transformed like the time component of the world four-vector this can be done consistently. After this principle has been promulgated the interest in superluminal phenomena revived.[2]

Up to now there is not the slightest experimental evidence of superluminal phenomena. Since there exists no final theory either, the only way to tackle superluminal phenomena is by extrapolation of existing theories. These theoretical considerations have, however, to meet severe conditions: they must be internally consistent, must not disagree with accepted principles and must not give results disagreeing with the results of established theories. This contribution intends to show that classical tachyons cannot be reconciled with existing theories, particularly with the special theory of relativity. It should be added that this standpoint is not accepted by some physicists.

Under classical tachyons faster-than-light particles are understood that can be readily emitted and detected or absorbed, and have sufficiently long decay time to travel over macroscopic distances. Tachyons that would in this respect resemble, e.g. pions, could be approximately described as classical. Our reasoning does not include very short lived or virtual tachyons in quantum field theory. In fact, such tachyons are present in every nonlocal field theory.

At first sight tachyons do not invoke an inconsistency. After all, there should be three types of particles: ordinary particles or bradyons with real positive rest mass having velocities less than c in all inertial frames of reference, luxons (photons, neutrinos,...) with zero rest mass havig velocity c in all inertial frames of reference, and tachyons with imaginary rest mass having velocities greater than c in all inertial frames of reference. Thus, c is the lower limit of the velocity for tachyons and their rest mass is a parameter only that cannot be measured directly. So tachyons cannot be get by any means accelerating bradyions over the velocity of light, they must be created and emitted as, e.g. neutrinos in β decay.

Owing to the reinterpretation principle concepts like tachyon emitter or tachyon detector are not invariant. In some frames of reference, i.e. for $v>c^2/V$, they must be interpreted as antitachyon detector or antitachyon emitter, respectively. But this as such does not contradict the relativity principle, as long as equations of physics are form-invariant.

To get the first argument against classical tachyons one has to consider causal cycles. Take an observer with a tachyon emitter which at a chosen instant emits a tachyon (event 1). This tachyon is absorbed, according to the first observer, by a tachyon detector of a moving second observer (event 2a). The second observer for $v>c^2/V$ interpretes this event as the emission of an antitachyon. Let he be instructed that immediately after this emission he should emit a tachyon towards the first observer (event 2b) to be detected there (event 3). It is a common idealization to regard events 2a and 2b as one event 2. The second observer does not encounter any difficulty in interpreting events 1 and 3 as effects of event 2 (Fig. 1). For the first observer, however, the emission of an antitachyon at event 3 which is an effect of event 2, which in turn is an effect of event 1, appears earlier in time than event 1. This situation is untenable since after the event 3 has happened the initial tachyon (even 1) may not be emitted.

Convincing evidence of the same kind can be obtained by considering stationary tachyon beams that are interrupted by a shutter. Let an observer in an inertial frame of reference have a tachyon emitter and a shutter at rest. From time to time he activates the shutter and this cuts the beam. If the shutter is closed tachyions are absorbed in it. If it is open tachyons are absorbed and detected at a moving tachyon detector. Now take an observer in an inertial frame of reference S' at rest with respect to this apparatus. Transform event after event from S to S'. In the case $v>c^2/V$ in the frame S' antitachyons are emitted by the shutter if it is closed. On the other hand, if the time sequence of events for the observer in S' is taken into account, antitachyons being emitted by his emitter, i.e. the tachyon detector according to the observer in S, the antitachyons are absorbed by the shutter on the opposite side (Fig. 2).

The inconsistency of both descriptons from the stanpoint of the first observer in S cannot be discussed away by noninvariance of concepts like emitter and detector. Thus, one is lead to the conclusion that there is no room for tachyons in special relativity if one accepts the weak form of the principle of macrocausality: an effect must happen in time after its cause.[3]

There are other objections against tachyons which we mention only in passing. It may to assumed that charged tachyons emit Cherenkov radiation even in vacuo and lose energy. Finally, a charged tachyon loses its entire energy and has zero energy and infinite velocity. But zero energy is not an invariant and in another frame of reference this tachyon would have positive total energy and would continue to radiate. The assumption that charged tachyons emit Cherenkov radiation in vacuo is, hence, open to doubt.

There is further indirect evidence against tachyons. In an extreme version of special relativity, i.e. extended relativity,[2] the relativity principle is generalized to superluminal phenomena. According to it a tachyonic world exists, symmetric to the bradyonic world, and two types of Lorentz transformations, subluminal, connecting two bradyonic or two tachyonic frames of reference and superluminal, connecting a bradyonic and a tachyonic frame of reference. It can be shown, however, that a real superluminal Lorentz transformation does not exist which would conform with space homogeneity and isotropy, light velocity invariance and/or the relativity principle[4]. The interior of the light cone cannot be mapped in a one-to-one way unto the exterior. Since space homogeneity and isotropy is well established on a macroscopic scale and special relativity is an accepted theory one concludes that the tachyonic world, if it exists, cannot be symmetric to the bradyonic one. This does not rule out tachyons on a microscopic scale or as virtual particles or as some kind of a collective phenomenon. It should be remarked that a complex superluminal Lorentz transformation is feasible[5].

To study real superluminal transformations a sixdimensional space-time with symmetric spatial and temporal parts was introduced[6]. In this case for a time-like state the measurable time is a function of three time components which are not measurable separately. On the other hand for a space-like state a measurable space scalar is a function of the three coordinates which are not measurable separately. In spite of the pleasant symmetry of this scheme, no appropriate function of three time components has been found yet that would give the measurable time. The proposed schemes, e.g. $t^2 = t_1^2 + t_2^2 + t_3^2$, do not give the experimentally verified relation between proper and coordinate time and the transversal Doppler effect.[7] Finally, the proposed general homogeneous Lorentz transformations are direct sums of three two-dimensional transformations and always commute. Hence, they do not lead to the Thomas precession which in turn gives an additional factor of $\frac{1}{2}$ in the spin-orbit interaction. This is experimentally well established through the measurement of spin-orbit splitting in atomic spectroscopy.[8]

Let us at the ened mention that for tachyonic fields with a Lorentz covariant equation the signal velocity does not exceed c. Take a Klein-Gordon bradion: in its complex ω plane there is a cut between the branching points $-mc^2/\hbar$ and $+mc^2/\hbar$ just below the real axis. For a Klein-Gordon tachyon the singularities appear rotated by 90^o and the cut extends between branching points $-imc^2/\hbar$ and $+imc^2/\hbar$ on the imaginary axis. Though all singularities are not contained in the lower half of the complex ω plane and though the phase and group velocity exceed c, the signal velocity does not exceed c.[9]

With this in mind we introduce a simple model for tachyons: optical barrier penetration at supercritical incidence, i. e. frustrated total reflection. At the passage of electromagnetic waves across a thin layer at subcritical incidence the singularities in the complex ω plane are simple equidistant poles on a line below the real axis and parallel to it. At supercritical incidence the singularities appear rotated by 90^o, i.e. simple equidistant poles on the imaginary axis. Though they are not contained in the lower half of the complex ω plane and though the phase and group velocity exceed c, the signal velocity does not exceed c. This can be shown simply by using Sommerfeld's consideration taking as medium the nuclei and electrons in void space. No wave front in it can travel faster than light in vacuo.[10]

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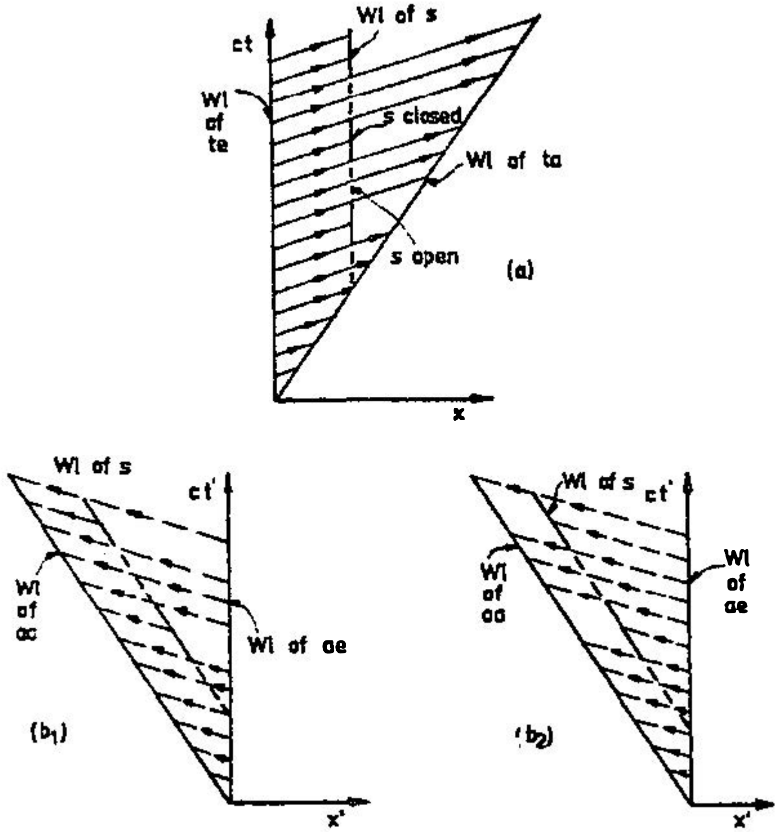

Figure 2. A modulated beam of tachyons in frame S : if the shutter is open tachyons are absorbed in the absorber, if it is closed they are absorbed in the shutter (a). Transforming event after event in another frame S' antitachyons are emitted by the shutter (b_1), whereas relying on the time sequence of events in frame S' antitachyons should be emitted by the emitter and absorbed by the shutter on the oposite side (b_2); wl stands for world line, a for absorber, e for emitter, s for shutter, t for tachyon and a for antitachyon.

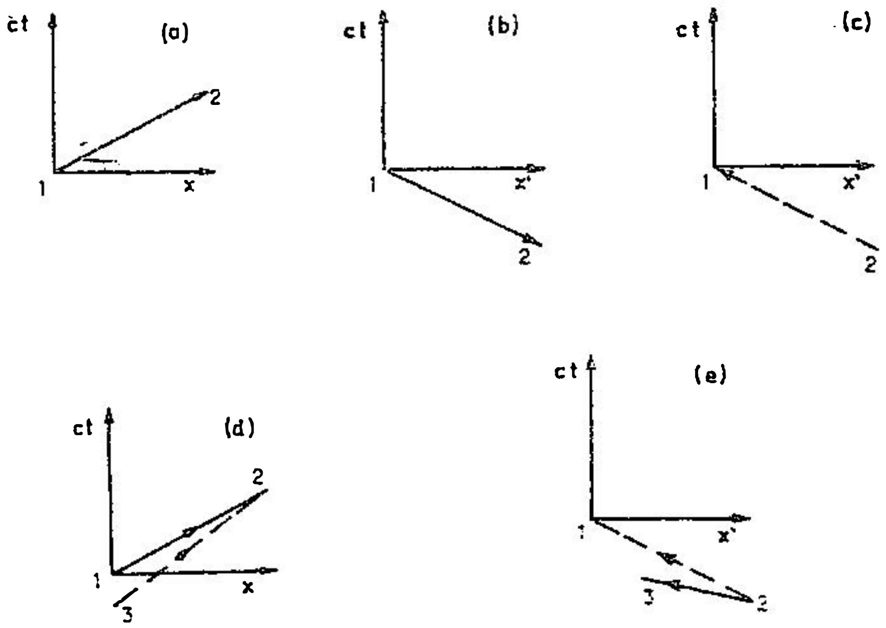

Figure 1. A tachyon in an inertial frame of reference S (a) may travel backwards in time in another frame of reference S' (b); according to the reinterpretation principle it is then interpreted as an antitachyon travelling forwards in time (c). A causal cycle leads to inconsistency : in frame S' events 1 and 3 are effects of event 2, in frame S, however, event 3 may happen before event 1, though event 2 is an effect of event 1 and in turn event 3 is an effect of event 2.