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The Tachyonic Antitelephone*

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The problem of detecting faster-than-light particles is reconsidered in relation to Tolman's paradox. It is shown that some of the experiments already under way or contemplated must either yield negative results or give rise to causal contradictions.

HYPOTHETICAL faster-than-light particles (tachyons) have recently received considerable attention, both theoretically[1–3] and experimentally.[4–6] Still, there are difficult questions of causality associated with faster-than-light signals. We hope to show that these have not been adequately resolved. In particular, it appears that at least some current attempts to produce and detect tachyons are foredoomed to failure on fundamental grounds.

In 1917 Tolman[7] presented an argument (Tolman's paradox) showing that if faster-than-light signals can be propagated, then communication with the past is possible. That is, they would comprise an "antitelephone."

Recently Bilaniuk, Deshpande, and Sudarshan[1] have attempted to answer this argument with a "reinterpretation principle." They note that a tachyon of negative energy $-E$ leaving point 1 at time t_1 and arriving at point 2 at an *earlier* time t_2 may be reinterpreted as a tachyon of energy $+E$ traveling from 2 to 1. Thus the earlier of the two events can always be viewed as an emission and the later as an absorption. They point out that the end of the tachyon's world line which appears "earlier" depends on the reference frame of the observer. That is, emission of a tachyon may be viewed as absorption by another observer. As we shall see, this statement is not sufficient of itself to refute Tolman's paradox.

Note that Tolman's paradox deals only with faster-than-light *communication*. It does not rule out tachyons which for some reason may not be used as a signaling system. There is no paradox associated with an unmodulated tachyon beam. Current theories deal mainly with noninteracting tachyons. The moment interactions are introduced, Tolman's paradox must be faced. It may reasonably be asked whether *any* interaction may be found that will satisfy all physical requirements, but we make no judgment on this matter.

Various experiments have been undertaken, however, on the assumption that some interaction exists. The results have been uniformly negative thus far. Still, it is proposed that further experimentation along the same lines be carried out "with improved apparatus."[3] Let us grant the assumption that the apparatus will work as it is supposed to. This alone will suffice to produce a paradox.

A typical experiment involves the following elements.

(1) A tachyon source that can be amplitude-modulated. In one experiment[4] such a source was to be provided by γ-ray bombardment of a lead target. Varying the γ-ray intensity would provide the required modulation.

(2) A tachyon detector. In another experiment[5] an ordinary semiconductor counter was used for this purpose.

(3) A velocity filter giving a monoenergetic beam. For this element, a double-focusing β spectrometer has been used.[5] Such a filter is not essential but is introduced only to simplify the analysis.

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[1] O. M. P. Bilaniuk, V. K. Deshpande, and E. C. G. Sudarshan, Am. J. Phys. **30**, 718 (1962).
[2] G. Feinberg, Phys. Rev. **159**, 1089 (1967).
[3] O. M. P. Bilaniuk and E. C. G. Sudarshan, Phys. Today **22**, No. 5, 43 (1969).
[4] T. Alväger and M. N. Kreisler, Phys. Rev. **171**, 1357 (1968).
[5] T. Alväger and P. Erman, 1965 Annual Report of the Nobel Research Institute (unpublished); see also Ref. 3 for details.
[6] B. Magliĉ and R. Schlüter (private communication to Bilaniuk and Sudarshan); see Ref. 3 for details.
[7] R. C. Tolman, *The Theory of Relativity of Motion* (University of California Press, Berkeley, 1917), pp. 54–55.

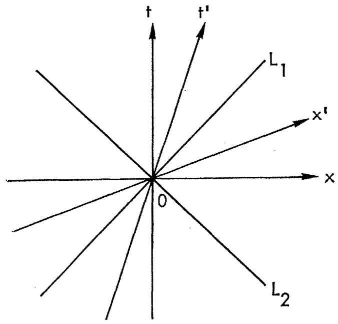

FIG. 1. Minkowski diagram illustrating rule for Lorentz transformation. The t' and x' axes are drawn so as to make equal angles with L_1.

Note that a positive result in such an experiment would already constitute a faster-than-light communication system. For if the detector response were totally uncorrelated with the modulation of the source, that could not be regarded as a positive result.

We do not consider signal-to-noise (S/N) ratio problems. If S/N is too small, we presume that the signal can be amplified. If N *necessarily* increases in proportion to S (as might possibly be implied by an argument of Feinberg[8]), then that would also imply a negative result to the aforementioned experiments.

To simplify matters, we will use geometrical arguments based on space-time diagrams. In Fig. 1 the lines L_1 and L_2 indicate the light cone. To make a Lorentz transformation to another frame (x',t') from (x,t), we simply draw x' and t' on this same diagram, retaining the property that the line L_1 or L_2 bisect the (Euclidean) angle between $0x'$ and $0t'$. This angle is not really an invariant property of the transformation; it appears as a result of representing Minkowski space by means of the Euclidean space of the paper but is nonetheless useful as a visual aid.

Now consider tachyon emission at the origin in the (x,t) frame. It appears as in Fig. 2. Because the tachyon moves faster than light, its world line lies outside the light cone. If $0x'$ is in the sector L_20P, the tachyon velocity falls between c and infinity for an observer in the (x',t') system. If $0x'$ is in the sector $P0L_1$, an observer in the primed system will see a velocity between negative infinity and $-c$. (For this observer, the temporal order of 0 and P is reversed.) The tachyon beam can take on any velocity *outside* the interval from $-c$ to $+c$ relative to a suitably chosen frame.

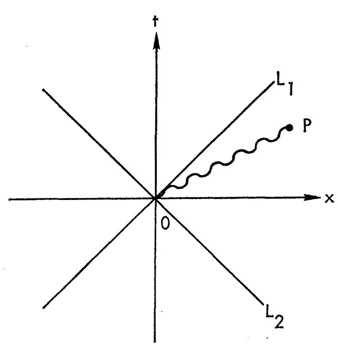

FIG. 2. A tachyon trajectory.

We assume the components (1)–(3) are combined to produce a source of tachyons with some standard velocity $V>c$ (called a V emitter) and a detector which registers the absorption of tachyons of velocity V (a V detector). Given these V emitters and V detectors, we now construct another type of transmitter and receiver.

We attach a series of emitters $(E_1,E_2,\ldots,E_n)$ to a conveyor belt, as shown in Fig. 3. The wheels of the conveyor are fixed on axes rigidly pinned to the laboratory table. By turning the wheels at an appropriate rate, the emitters can in principle be given any desired velocity between $-c$ and $+c$ as measured in the laboratory frame. We may also fix to the side of each emitter a small computer preprogrammed with a desired message to be fed into the modulator of the emitter's tachyon beam. This eliminates any difficulty associated with transmission of the message from the laboratory to the moving emitter. Let the whole system be considered as a new source, fixed in the laboratory frame, and let V' be the outgoing velocity. Then V' can be given any value outside the interval from $-c$ to $+c$.

Similarly, let the V sources on the conveyor belt be replaced with V detectors. Then the whole system will operate as a V' detector, where V' covers the same velocity range as before. The incoming message is read by the attached computers, and recorded for the benefit of the experimenter, to be read by him after the conveyor belt is brought to rest.

Our two experimenters, A and B, can be given each a V' emitter and a V' detector. For simplicity, let them both be at rest in the same reference frame, though separated by a finite distance. Finite delays are involved in the programming of A's computer, in setting his conveyor belt in motion, in bringing B's to rest, and in reading out the received message. However,

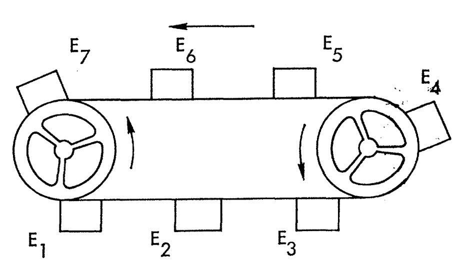

FIG. 3. Device for transmitting signals by means of a modulated tachyon beam. Emitters E_1, E_2, ... (each accompanied by controlling computer) are mounted on conveyor belt turning on wheels with appropriate velocity. A corresponding receiver is constructed by replacing emitters by detectors D_n.

[8] See Appendix B of Ref. 2.

these are independent of the distance between A and B. They can be made negligible by making the latter sufficiently large.

For very large positive V', this arrangement permits an arbitrarily rapid system of communication. It is this feature which makes the tachyon concept so striking. But even more surprising, if V' is negative, the signal goes backward in time (see Fig. 4).

Bilaniuk and Sudarshan have suggested that this is not the way the experimenters will view events. It is clear to A that the point B_1 is temporally antecedent to A_1, so that the trajectory A_1B_1 represents a tachyon emitted at B_1 and absorbed at A_1. It is argued that this reinterpretation eliminates any problems associated with the possibility of an experimenter sending signals into his own past.

What Bilaniuk and Sudarshan had in mind was a situation in which A and B exchange a single tachyon. Here, however, we are dealing with a modulated beam of arbitrary length used to transmit a message. For example, let A be William Shakespeare and B Francis Bacon, and let V' be negative. If Shakespeare types out *Hamlet* on his tachyon transmitter, Bacon receives the transmission at some earlier time. But no amount of reinterpretation will make Bacon the author of *Hamlet*. It is Shakespeare, not Bacon, who exercises control over the content of the message.

For any tachyon trajectory (any spacelike interval) the time ordering of the end points is relative to the reference frame. But the direction of *information transfer* is necessarily a relativistic invariant. An author's signature, for example, would always constitute an invariant indication of the source.

Note that in this context, the causal ordering of events is established independently of the temporal ordering. For, in general, there are ways of distinguishing between cause and effect without reference to the timing.[9] Indeed, in ordinary situations we are often able to distinguish between cause and effect even when the time intervals involved are imperceptibly short. It takes no special equipment, for example, to infer that a lamp is controlled by its switch. In the *Hamlet* example, the distinction can be made because only one of the participants is in the controlling position.[10]

[9] H. Reichenbach, *The Philosophy of Space and Time* (Dover, New York, 1958), Sec. 21.

[10] R. G. Newton, Phys. Rev. **162**, 1274 (1967).

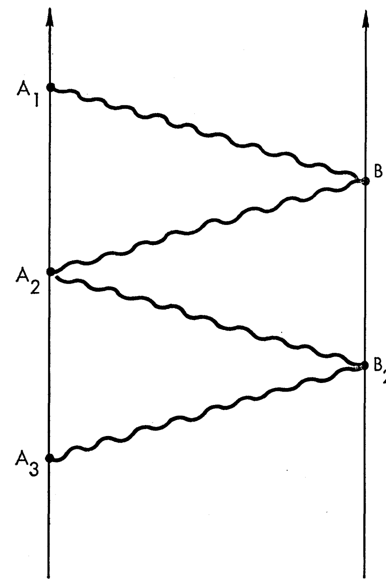

FIG. 4. A and B use tachyonic antitelephones to communicate backwards in time. A message sent by A at 3:00 o'clock (A_1) is received by B at 2:00 o'clock (B_1), etc.

The paradoxes of backward-in-time communication are well known. Suppose A and B enter into the following agreement: A will send a message at three o'clock if and only if he does *not* receive one at one o'clock. B sends a message to reach A at one o'clock immediately on receiving one from A at two o'clock. Then the exchange of messages will take place if and only if it does not take place. This is a genuine paradox, a causal contradiction.

Yet it is just this type of paradox that would be made possible by the experiments referred to above. In each case the supposed tachyon sources employed could be modulated, and these modulations received by the detectors used. If these experiments had detected any tachyons emitted by the sources, elementary modifications such as those discussed here could be made. An "antitelephone" could be built, and we would be faced with the Tolman paradox. Unless some truly radical solution is found to this paradox, we must conclude that tachyon experiments of this sort can only yield negative results.