

MORE ABOUT TACHYONS

Not so fast! say critics of the May article in which Bilaniuk and Sudarshan offered the arguments for faster-than-light particles. Their letters raise questions about causality and interactions. The original authors contribute a reply.

OLEXA-MYRON BILANIUK, STEPHEN L. BROWN, BRYCE DeWITT, WILLIAM A. NEWCOMB, MENDEL SACHS, E. C. GEORGE SUDARSHAN, SHOICHI YOSHIKAWA

"Anything that is not forbidden is compulsory," says Murray Gell-Mann's half-facetious totalitarian principle. What then about faster-than-light particles called "tachyons"? In their May article¹ Olexa-Myron Bilaniuk and E. C. George Sudarshan argued that valid solutions of Albert Einstein's relativity equations describe such particles. Thus if Einstein's equations are accurate descriptions of the physical universe and if solutions not forbidden are compulsory, tachyons must exist.

The May article stirred up a flurry of correspondence directed largely at two questions: Are the tachyon solutions valid? Do they have significance in our real world? From those letters we have chosen five that represent the principal viewpoints. With them we publish Bilaniuk's and Sudarshan's reply to their commentators.

Real force, imaginary mass

The May article by Bilaniuk and Sudarshan presented a very interesting and provocative discussion of the possible existence of particles that can travel faster than light. After presenting their case, the authors pointed to several objections that have been raised against their proposal, and they showed how their own viewpoint answered these objections. Some further objections that could be raised, however, are not mentioned by the authors. I should like to discuss them in this letter.

The authors base their argument on the relationships among energy, mo-

mentum, mass and speed that follow from the mechanics of particles in special relativity theory. They point out that since both energy and momentum depend on the mass factor, $M_0/(1 - v^2/c^2)^{1/2}$, the conserved quantities could remain real numbers if simultaneously $v^2/c^2 > 1$ and m_0 is replaced with the purely imaginary proper mass im^* . The argument is that since energy and momentum—not inertial mass—are the observables, only these quantities must have a description in terms of real numbers.

A tacit assumption here is that the appearance of inertial mass originates in the expressions for energy, momentum, etc. But this is not actually true, according to the full meaning of relativity theory. For in Einstein's original approach, special relativity is only a special case of general relativity. (Indeed, the adjective "special" implies this fact). In general relativity theory energy and momentum are not defined quantities! The conservation laws are in fact only the asymptotic features of the general formalism in the limit of a local domain. However, inertial mass is defined here in global terms. It relates to the metrical field $g^{\mu\nu}(x)$ through Einstein's field equations. Thus inertia is a more general property of matter than energy or momentum. The inertia of matter appears in terms of a (continuously distributed) field on the right

side of Einstein's equations. The metrical field solutions, $g^{\mu\nu}(x)$ appear on the left side of these equations. Now if the inertial mass of any bit of matter (in the proper frame of reference) should be represented by a purely imaginary number, it would follow that the corresponding metrical field solution of Einstein's equations (in the same frame of reference) must also be represented by a set of imaginary numbers. But this would be inadmissible for several reasons. One important reason is that in the local limit, the metric tensor must approach the diagonal form $(1, -1, -1, -1)$ that characterizes special relativity theory. The latter, of course, is a set of real numbers. If $g^{\mu\nu}$ is represented by a set of purely imaginary numbers in its global description, it could not approach a set of real numbers in a continuous fashion under any circumstances! Physically, the continual approach of $g^{\mu\nu}$ toward the Lorentz metric in the local domain corresponds to the diminishing effect that one bit of matter (in this case the tachyon) would have on other matter.

The gist of this argument is that the inertial mass term m_0 derives from a more primitive relation than the expressions of energy and momentum in special relativity. Once the general relation that relates inertia to the global features of a physical system is found, one can take the asymptotic

limit and derive the value for the mass of a bit of matter in the local domain. Only at this stage (in principle) does one insert this parameter in the energy and momentum expressions. But the original general relation that identifies inertia with the metrical field necessarily requires that the proper mass be represented by a purely real number. In this case, the further requirement that the energy, momentum, etc., be represented by real numbers would *not* permit v/c to be greater than unity.

One further argument against the existence of tachyons has to do with the fact that one does not measure energy and momentum in any experiment; one rather measures the energy and momentum *transfer*, a *change* of energy-momentum. But a change in energy-momentum has to do with *force*—the force that causes an interaction between matter and matter and, in turn, relates to the corresponding change of state of motion of the interacting matter. Now if inertial mass relates to a measure of the resistance to the change in the state of motion of matter and if we define the force exerted by matter on matter

(the momentum transfer that is mutually exchanged) in terms of real numbers, then the mass itself must also be represented by a real number. Otherwise an imaginary-mass particle would not interact with a real-mass particle. In particular, if one part of this mutual interaction is a measuring apparatus—which we have already used to detect real-mass particles (for example, a cloud chamber)—then it should not be able to detect imaginary-mass particles.

At the root of this objection is the omission in the paper by Bilaniuk and Sudarshan of discussion of interaction between the tachyon and any other matter. But it is *essential* in this problem to introduce the description of interaction because of the necessary appearance of matter with real mass to interact with the faster-than-light particles. My argument above implies that as soon as this interaction is taken into account, the conclusion is reached that (within the framework of relativity theory) no matter described by real mass could respond in any way to the tachyon. From this point of view, then, the tachyon must remain in a theoretical domain

that is beyond the domain of physics.

My argument has been based on a look at the consistency of the tachyon description within the theory of relativity. Therefore I do not at all disagree with the attempt to find faster-than-light particles. But I do disagree with the authors' interpretation of the results of such experimentation. For if such particles should be found, I should have to conclude (in contrast with the authors' contention) that the theory of relativity would have been refuted.

MENDEL SACHS

State University of New York, Buffalo

Tachyonic Cerenkov radiation

I should like to raise one question in connection with the recent article by Bilaniuk and Sudarshan. The authors alleged that a charged tachyon, by the emission of Cerenkov radiation, would ultimately enter a "transcendent" state of infinite velocity or zero energy. However, this would not appear to be a relativistically invariant condition. An infinite-velocity trajectory is one that is orthogonal (in the space-time sense) to the time axis of one's reference frame, and it will not be orthogonal to the time axis of another frame. How can this be reconciled with the principle of relativity?

WILLIAM A. NEWCOMB

Lawrence Radiation Laboratory,
Livermore

THE AUTHORS

Mendel Sachs, professor at the State University of New York, Buffalo, is now on leave at the Department of Applied Mathematics and Theoretical Physics, University of Cambridge, England.



William A. Newcomb, plasma physicist at Livermore, has BA and PhD degrees from Cornell and formerly worked at Project Matterhorn, Princeton.



Shoichi Yoshikawa is at the plasma-physics laboratory, Princeton. He has a BS from the University of Tokyo and a PhD from MIT.



Bryce DeWitt is a specialist in quantized gravity and a professor at the University of North Carolina. His three degrees are from Harvard University.



Stephen L. Brown, who does operations research for the Stanford Research Institute, got a PhD at Purdue as a high-energy theorist.



Olexa-Myron Bilaniuk, professor at Swarthmore, was born in the Ukraine and educated in Belgium and at the University of Michigan.



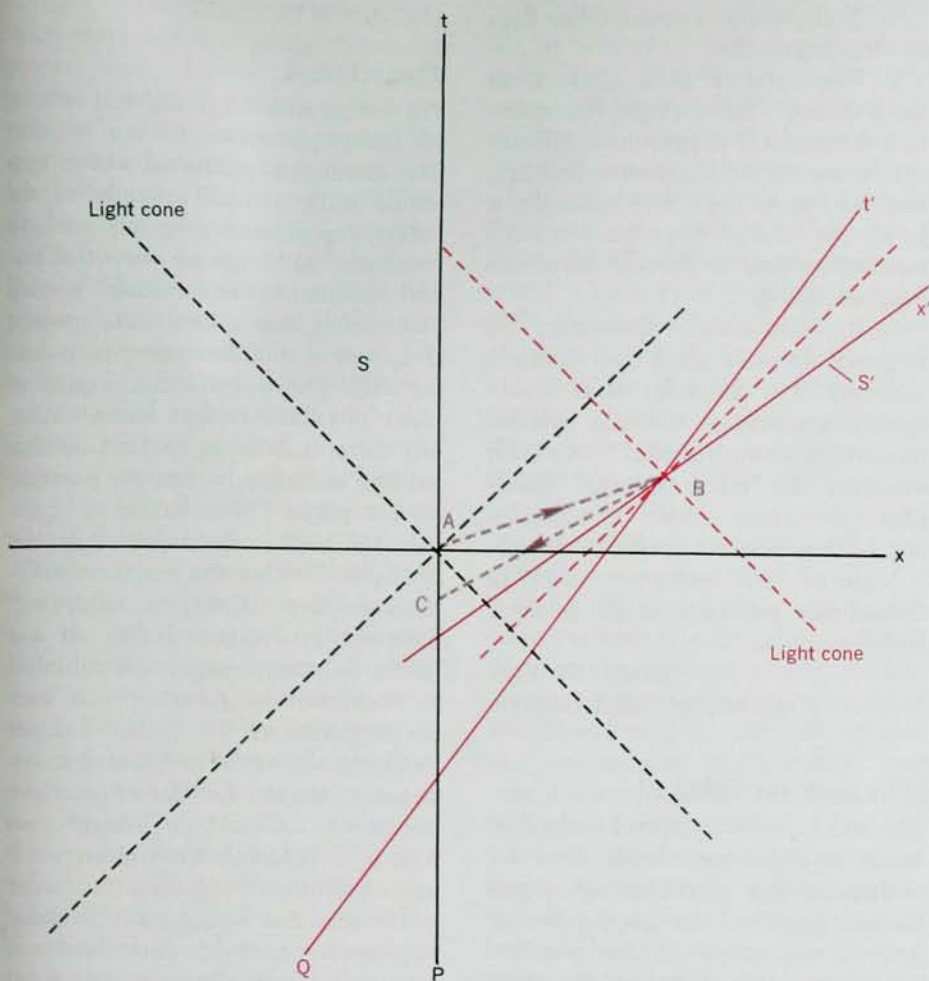
E. C. George Sudarshan came from India and the University of Madras to the University of Rochester. He is now a professor at University of Texas, Austin.



Violation of causality

The article by Bilaniuk and Sudarshan is well written and the exposition of tachyon theory is almost perfect. This, however, permitted me to conceive the following objection: If tachyons are to be produced or absorbed by tardyons or luxons, the causality principle is not upheld. My objection does not exclude the possibility that tachyons may interact with other species in an *uncontrolled* manner. (I will clarify the uncontrolled manner in the last paragraph.)

The causality principle is to be put in the following form: If an event A causes the event C at the same location in a coordinate system S yet earlier in time (figure 1), the causality principle is violated. Whether the event C is the emission of a tachyon or absorption of a tachyon is immaterial. What I would like to point out is that by transmitting a tachyon



CAUSALITY VIOLATION. Effect in frame S appears to precede cause in S through signals to and from frame S' moving with respect to S. —FIG. 1

at $t = 0$, the observer P in the coordinate system S can induce the emission of another tachyon at $t = -t_0$ (< 0). This seems to me a very clear case of the violation of causality. It hardly requires any explanation. I shall sketch the argument. Observer P sends a tachyon at $t = 0$ to another observer Q located at B on a moving coordinate S'. Observer Q then finds that a negative-energy tachyon is absorbed at B; that is, a positive-energy tachyon is emitted in the negative x' direction. As soon as he notes the emission of this tachyon, he sends another tachyon with a faster velocity along the negative x' axis. This second particle is then absorbed by an absorber located at C. The observer P finds that a positive tachyon was emitted at C ($t = -t_0$). Clearly the emission of a tachyon at C was caused by the decision of the observer at A ($t = 0$). Hence, the causality principle was violated.

If we can control the interaction between a tachyon and other particles

in any way (such as blocking the motion of a tachyon), we can violate the causality principle. For example, if we let observer P pass only a tachyon with a specified velocity to reach observer Q and if we let Q allow the passage of only those tachyons faster than the first tachyon to reach P, eventually P finds a passing of a tachyon earlier in time because another tachyon with a specified velocity passes later in time.

SHOICHI YOSHIKAWA
Princeton University

Reinterpretation won't work

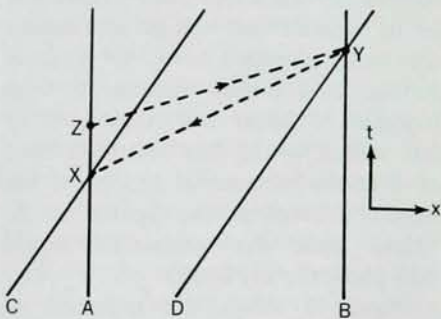
Your authors Bilaniuk and Sudarshan cannot get off the hook as easily as they pretend they can in their article. I refer to their claim that by reinterpreting negative-energy tachyons traveling backward in time as positive-energy tachyons traveling forward in time they can avoid the causality objections against the tachyon hypothesis. This is simply not true, and

it does not require sophisticated arguments or the invocation of thermodynamical irreversibility and quantum-mechanical uncertainties to prove it.

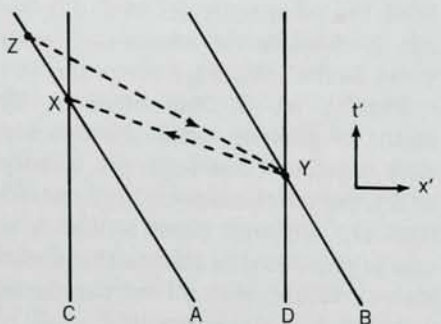
First of all, if tachyons exist, they must interact with normal matter. If they interact with normal matter, it must be possible, in principle, to produce them in a beam. Moreover, it must be possible to modulate this beam at the source, and hence to send a directed signal faster than light. For purposes of the present argument it is sufficient to represent such a signal as a spacelike line in spacetime. An actual signal would be a striped ribbon since time is required both to emit it and to receive it. But if emitter and receiver are far enough apart, the width of the ribbon can be neglected.

Let A and B be two observers, both at rest in an inertial frame (x, t) . (We suppress coordinates y and z for simplicity.) Let A emit a modulated burst of tachyons at the space-time event Z, as shown in figure 2. Let this signal be received by B at the event Y. Because Y is later than Z, in the common inertial frame of A and B, both observers agree that A is the emitter and B the receiver, and that positive energy has been transmitted from A to B.

Now suppose a third observer D



IN ONE FRAME Y comes after X and Z. Dots show tachyon signals. —FIG. 2



IN OTHER FRAME event Y precedes events X and Z. —FIG. 3

is passing in the vicinity of B near Y, with a relative velocity v ($<c$). In figure 2 the world lines of B and D are drawn as if they intersected at Y; the intersection could actually take place a little later. Suppose that during the time of intersection (that is, while they are fairly close to one another) B transmits to D the information he has received (by way of the tachyon signal) from A, and suppose this transmission takes place by means of ordinary photons. Because photons are quite conventional carriers of information, there will again be no ambiguity about who is doing the emitting and who the receiving. On the other hand, by the relativity principle, the laws of physics must be the same for D as they are for A, and hence he will be perfectly capable of immediately sending back to A, with an identical tachyon transmitter of his own, the information he has received from B.

Since the world lines of tachyons are spacelike, there exists a range of values for v , determined by the tachyon velocity, for which the second tachyon signal appears, from the point of view of observers A and B, to propagate into the past. Suppose v is in this range. Then arguments will arise, between A and B on the one hand, and D on the other, about who is doing the sending and who is doing the receiving. To avoid such arguments let us suppose that instead of sending the tachyon signal to A, D sends it instead to a fourth observer C who happens to be at rest relative to D but whose world line intersects that of A at the moment of receipt of the signal, denoted in the figures by X. (Here again the intersection *could* take place slightly later.)

Figure 3 shows the sequence of events as viewed in the common inertial frame of C and D, denoted by (x', t') . Because event X is later than Y in this frame, C and D agree that D is the emitter and C the receiver. Since the other observers, A and B, are not involved in the transaction, their views on the subject are irrelevant.

Finally, let C transmit to A by means of photons, while the two are close together (that is, in the vicinity of X), the information he has received from D. The net result is that A is now in possession of information about his own future, with all the paradoxes that such knowledge entails.

I can think of only three ways to avoid such paradoxes:

1. Tachyons never exist other than as virtual particles.

2. The universe as a whole is so finely tuned (for example, by quantum mechanical interference effects) that whenever information is sent into the past, as in the above example, it is always wiped from the receiver's memory in time to prevent paradoxes from occurring.

3. Emission and absorption of tachyons can take place only between members of a restricted class of observers possessing velocities relative to some *preferred* inertial frame (for example, the frame of the "fixed" stars, or some other cosmological frame) less than some critical value.

None of these restrictions holds in the scheme put forward by Bilaniuk and Sudarshan.

BRYCE DEWITT

University of North Carolina

Why wait for light?

The article by Bilaniuk and Sudarshan seems to me a remarkably clear exposition of the possibility of superluminal particles. In reading the article, I was struck by the practical implications that such particles might have. (I have not kept sufficiently current with the research in the subject to know whether these implications have already been discussed.)

Briefly, the argument is as follows: Class II particles (luxons) can be produced, modulated and detected by tardyon observers. The tachyon properties discussed imply that similar control could be exercised over Class III particles (tachyons), especially through the intermediation of luxons, as in the Cerenkov-detection proposal. Tachyons could therefore be used for communication systems. Such communication systems would be useful only where ordinary electromagnetic radiation is too slow, as in interstellar communication. Finally, it would seem likely that any extra-terrestrial life of high technology would be aware of tachyons (if they exist) and would use them for communications instead of waiting centuries for replies at the speed of light. Perhaps, then, the Project OZMA concept of monitoring electromagnetic radiation for intelligible patterns will turn out to have much less potential for interstellar contact than a tachyon monitoring system.

STEPHEN L. BROWN

Stanford Research Institute

The rebuttal

We are gratified by the response of so many physicists to our article.¹ The comments published above constitute only a small sample of the letters, reports and preprints we have received. Although we knew that several points in our article needed elaboration, that others were speculative, and that a few were pure conjectures, yet we did not expect so many physicists to take notice. After all, there is little in that article that we had not already said, for example, in our paper "Meta-Relativity" published in 1962 in the *American Journal of Physics*.² Then the reaction was entirely positive. A very favorable commentary by Angus Hurst on our "Meta-Relativity" paper was published in *Mathematical Reviews*.³ A team of physicists at the Nobel Institute in Stockholm undertook the first systematic search for faster-than-light particles.⁴ Gerald Feinberg⁵ and Arthur C. Clarke⁶ have given excellent exposition of our ideas to a wider audience. But because the causality arguments remained unresolved and because nothing at all was said about tachyon interactions, such a favorable



reaction seemed almost too good to be true. As Bryce DeWitt puts it, we did not expect to "get off the hook that easily."

After having studied the above letters and all the other correspondence quite carefully, we are now convinced more than ever that our extension of the special theory of relativity to include superluminal particles (metarelativity) is viable and that we can satisfactorily answer all objections raised so far.

General relativity. Let us first deal with the point questioned by Mendel Sachs. He argues that our theory is inconsistent with the general theory of relativity. We disagree. We had pointed out that for energy and momentum to be real, the proper mass of a tachyon must be imaginary. Sachs contends that an imaginary proper mass raises difficulties regarding gravitation because gravitation couples to inertia. Let us recall that the relativistic gravitational field is

coupled to the density of energy and momentum and *not* to the density of proper mass. In the limit of slowly moving tardyons (ordinary massive particles) one can approximate the relativistic interaction by a Newtonian interaction using the proper mass density but only in this special case and in this special limit. It just happens that under these circumstances the proper mass density and the energy density are equal (apart from the c^2 factor). As long as the energy and momentum of tachyons are real (that is, the proper mass is imaginary) tachyons present no anomaly regarding gravitational interactions in general relativity theory.

Transcendent tachyons. William Newcomb's question is quite intriguing. Indeed, a charged tachyon that has reached its zero-energy "transcendent" state in one frame still has some energy left in some other frame moving with a velocity w relative to the first; hence in that frame the tachyon can keep on radiating. This contradiction can be resolved by recalling that according to an observer in the second frame the sign of the energy and the direction of travel in time will be reversed (in accordance with the switching principle) when the tachyon



reaches a velocity c^2/w relative to the first frame. The events that lead to a transcendent tachyon in one frame look like a head-on collision and annihilation of a tachyon and an anti-tachyon in another. Thus Newcomb is quite correct in pointing out that the transcendent state would not be a relativistically invariant condition. There is nothing disquieting about this because it is not the description of events that must remain invariant when we go from one frame to another, only the laws that govern these events.

Causality. As we pointed out in our PHYSICS TODAY article,¹ causality objections against superluminal particles are by far the most subtle, and much room for reflection remains in this regard. The questions raised by Shoichi Yoshikawa and DeWitt bear this out. Both are refined versions of earlier formulations of the causality paradox. Yoshikawa follows closely Richard Tolman's original arguments,⁷

and DeWitt essentially parallels chapter 28 of David Bohm's monograph on relativity.⁸ Because the earlier presentations ignored the fact that a signal traveling backward in time carries negative energy, they were incomplete and could be dismissed as such. Yoshikawa and DeWitt, on the other hand, do allow for the sequence reversal. They point out that in principle the flow of information can be opposite to the direction of travel of a tachyon beam conveying the information. This is a novel conclusion. They show that if such counterdirected information flow were indeed possible, the closed causal loop would be reestablished notwithstanding our switching principle.

In devising gedanken experiments on superluminal communication it is necessary to take very careful account of cosmological boundary conditions. While assuming the existence of certain transmitters and receivers, we may not at the same time ignore the presence of other matter in the universe. In particular we have to make certain assumptions regarding the tachyon background. The simplest assumption is that the number of tachyons crisscrossing the universe is finite. Moreover, we know that as far as tardyons are concerned, this situation would still hold for an observer in a different inertial reference frame. Such would *not* be the case for tachyons.

Preferred frame. To see why the case is different with tachyons, consider two pieces of equipment, one a large emitter and the other a large receiver. Let both be located in what we shall call the "standard" frame where the flux of tachyons coming from distant regions of the universe is finite. Under such circumstances, however large the detector, the number of tachyons that it will detect per unit time is finite. On the other hand, the number of tachyons the large emitter can emit is at our disposal and can be made arbitrarily large. It should be noted that as long as the observations are made from the standard frame, the above situation holds irrespective of whether the emitter-receiver system is stationed in the standard frame or whether it is carried in a fast moving rocket. Furthermore the assumption that the number of tachyons streaming into the standard frame from distant random sources is finite implies that the number of tachyons within a certain mo-

mentum range is also finite. We know that corresponding to this momentum range there exists a reference frame in which the role of emitter and receiver for tachyons is interchanged. An observer in that frame would find that as far as he is concerned there is a limit to the number of particles that can be emitted within a velocity range greater than a certain critical value but that an arbitrarily large number of such particles can be detected by a suitable piece of apparatus.

Refutation. Let us assume now a standard frame S_0 in which the tachyon background is zero. This will simplify our arguments without any essential loss of generality. While the tachyon background in S_0 is zero, the observer P_0 can still emit any number of tachyons of any velocity $v > c$. For another observer P_1 moving with a velocity $w < c$ relative to the standard frame this situation implies the impossibility of his emitting tachyons with a velocity greater than a certain threshold velocity $u_1 = c^2/w$. Instead he will see a flux of tachyons with velocities $u > u_1$ streaming into his receiver every time he activates it. This is so because an arbitrary number of tachyons can be emitted by P_0 . Every time P_1 activates his receiver (which is an emitter for P_0), it will register incoming tachyons. Conversely, P_1 will not be able to use his emitter (receiver of P_0) for sending tachyons with a velocity $u > c^2/w$ towards distant regions of space because doing so would mean that observer P_0 would register tachyons coming from infinity every time he opens his detector; such an action is contrary to our assumption that no tachyons from distant sources exist for the observer in the standard frame. In dealing with the causality paradoxes it is not necessary to assume that one of the observers is at rest in the standard frame. But by referring to this frame, we can determine which of the signals of the vicious causal cycle can not be sent. In other words, irrespective of the state of motion of the emitter, only those signals that carry information *and* energy in the same direction as seen in the standard frame are possible. Under such circumstances *no causal loops could arise* and no "anti-telephone," such as proposed by Gregory Benford, David Book and William Newcomb,⁹ could be built.

The above suggested resolution of the refined causality arguments cor-

responds to the third way by which, according to DeWitt, causality paradoxes can be avoided. *It is in no way incompatible with our generalization of the special theory of relativity.* However, a question that may be in order is whether the assumption of existence of a preferred frame, such as S_0 above, is consistent with the postulates of special relativity. After all, is not the exclusion of a preferred frame what relativity is all about? *No, it is not.* The postulates of special relativity require the laws of physics, including the speed of light, to be the same in all inertial frames. They do not preclude the existence of cosmological boundary conditions that permit us to single out a particular local frame as a preferred reference system. For example, the frame of reference in which the cosmic 3-K black-body radiation is isotropic could be considered a preferred frame that can be distinguished from all other frames.

Other avenues. The approach we suggest above is by no means the only way by which hypothetical superluminal particles can be reconciled with the logical requirements of the causality principle. For example, Raymond Fox, Charles G. Kuper and Stephen G. Lipson¹⁰ attempt to accomplish this by extending the method of Arnold Sommerfeld and Léon Brillouin.¹¹ Another simple, if somewhat brute force, solution is offered by Ray Skinner¹² who simply postulates that negative-energy energy-momentum transfers must be unsuitable for signaling.

Although it is not our feeling that any radical changes in physical concepts are necessary to accommodate the tachyon hypothesis, there are some serious physicists who shrug off the causality objection by simply saying, "So what?" Roger G. Newton¹³ and Paul L. Csonka¹⁴ are doing precisely that. They feel that no precepts of logic would be violated if the temporal order of cause and effect were sometimes reversed. Whichever approach will ultimately prove the best, we are convinced that causality objections offer no compelling grounds for desisting from further theoretical and experimental work on metarelativity.

Acausal experiments. This assertion is particularly true of searchers for "single events" for which the causality arguments, such as raised above and elsewhere,^{9,15} are irrelevant. An excel-

lent example of this type of experiment is the search for the reaction $p + p \rightarrow p + p + T$ (tachyon) which Bogdan Maglic, James Norem, Howard Brody and their collaborators have told us they propose to carry out at the Princeton-Penn accelerator. In some other frame this reaction may appear as $p + p + T \rightarrow p + p$. Since data to be recorded by their missing-mass technique¹⁶ pertain to tardyon channels only, this type of experiment would reveal the presence of tachyons without forcing them to disclose the direction of their path in time. [The experimenters are placing their proton detectors at 120 deg, whereas the maximum angle for protons from the $p + p \rightarrow p + p + X$ (real-mass particle) reaction is 90 deg. Only tachyons having a proper mass between 0.5i and 3.5i GeV could lead to emission of protons in the 120 deg direction.] Providing the experiment is not thwarted by unexpected background problems, Maglic and his collaborators hope to be able to infer the existence of tachyons even if the cross section for their production is as small as 10^6 times smaller than that for the $p + p \rightarrow p + p + \pi^0$ reaction. An earlier $p + d \rightarrow \text{He}^3 + X$ missing-mass search for tachyons,¹⁶ also initiated by Maglic, was inconclusive because the cross section for production of He^3 turned out to be extremely low (about 10^{-34} cm² at 3 GeV). Maglic holds out much more hope for the $p + p \rightarrow p + p + X$ reaction.

Other experiments unaffected by causality objections include the bubble-chamber search by Charles Baltay and collaborators¹⁷ for the reactions $K^- + p \rightarrow \Lambda + T$ and $p^- + p \rightarrow \pi^+ + \pi^- + T$ (we use p^- for antiproton), and the search for the reaction $\pi^- + p \rightarrow n + T$ that Michael Kreisler tells us he is carrying out. In some other frame these reactions may look like $K^- + p + T \rightarrow \Lambda$, $p^- + p + T \rightarrow \pi^+ + \pi^-$, and $\pi^- + p + T \rightarrow n$, respectively.

Superluminal physics. We are very much encouraged by imaginative suggestions such as that of Stephen Brown above and that of John W. Rhee,¹⁸ but we prefer to withhold our comment on them until tachyons actually have been detected and their properties are better understood.

In conclusion we wish to say that we are pleased to see our sentiments echoed in a comment to us from Iwo Bialynicki-Birula to the effect that the concept of faster-than-light

particles is not really that unorthodox. He reminds us that all concepts of nonlocal interactions in field theory imply the existence of some agent carrying the interaction over space-like distances and thus nonlocal field theories have implicitly assumed the existence of some sort of superluminal entity. Notwithstanding questions of causality, we hope to have shown² that the special theory of relativity can be consistently generalized to accommodate faster-than-light particles.

By way of encouragement to all those working or contemplating work in the field of superluminal physics let us quote the adage coined by David Farragut at Mobile Bay: "Damn the torpedoes; full speed ahead!"

OLEXA-MYRON BILANIUK

Swarthmore College

E. C. GEORGE SUDARSHAN

University of Texas at Austin

References

1. O. M. Bilaniuk, E. C. G. Sudarshan, *PHYSICS TODAY* **22**, no. 5, 43 (1969).
2. O. M. P. Bilaniuk, V. K. Deshpande, E. C. G. Sudarshan, *Am. J. Phys.* **30**, 718 (1962).
3. C. A. Hurst, *Math. Rev.* **26**, 667 (1963).
4. T. Alväger, J. Blomqvist, P. Erman, 1963 *Annual Report of the Nobel Research Institute*, Stockholm, pp. 95-97.
5. G. Feinberg, *Phys. Rev.* **159**, 1089 (1967).
6. A. C. Clark, *The Promise of Space*, Harper & Row, New York (1968) p. 299.
7. R. C. Tolman, *The Theory of Relativity of Motion*, University of California Press, Berkeley (1917) p. 54.
8. D. Bohm, *Special Theory of Relativity*, W. A. Benjamin, New York, 1965, pp. 155-160.
9. G. A. Benford, D. L. Book, W. A. Newcomb, Lawrence Radiation Laboratory Report UCRL-71789, Livermore, (1969).
10. R. Fox, C. G. Kuper, S. G. Lipson, *Nature* **223**, 597 (1969).
11. A. Sommerfeld, *Physics Z.* **8**, 841 (1907); L. Brillouin, *Ann. Physik* **44**, 203 (1914).
12. R. Skinner, *Relativity*, Blaisdell Publishing Co, Waltham, Mass (1969) p. 189.
13. R. G. Newton, *Phys. Rev.* **162**, 1274 (1967).
14. P. L. Csonka, *Phys. Rev.* **180**, 1266 (1969).
15. W. B. Rolnick, *Phys. Rev.* **85**, 1105 (1969).
16. B. Maglic et al, *Bull. Am. Phys. Soc.* **14**, 840, (1969).
17. C. Baltay, G. Feinberg, N. Weh, R. Linsker, US AEC Report NYO-1932(2)-148(1969).
18. J. W. Rhee, Technical Report No. 70-025, Center for Theoretical Physics, University of Maryland (1969). □