

torial attempted only to point out that the schedule he proposed for the cuts and his statements about an "orderly transfer" are contradictory. The Senator has created even further concern among scientists with his comment that, if Congress chose to eliminate rather than transfer the funds in question, it "would not be a national calamity."

More on tachyons

In connection with the article "Beyond the Light Barrier" by O-M. Bilaniuk and G. Sudarshan in the May, 1969 issue, readers of *PHYSICS TODAY* might be interested to know of a further tachyonic domain within relativistic theory.

For decades many physicists have believed that a relativistic Newtonian-like particle dynamics, in the old and simple instantaneous-action-at-a-distance sense, is out of the question. It is, however, well within possibility, and it affords scope for many things, superlight velocities included.

A few years ago¹ the conditions were worked out for the "forces" F_i in order that a completely Newtonian-looking particle dynamics $\ddot{x}_i = F_i$ (functions of coordinates and velocities) be Lorentz-covariant. The covariance certainly can not leap to the eye when you have once figured out some suitable F_i 's; but it is equally certain there, when the forces are tooled up right.

The simplest known example² (for two particles in one dimension) is

$$\ddot{x}_1 = \mp \frac{1}{2} \frac{(\dot{x}_1 - \dot{x}_2)^2}{(x_1 - x_2)}$$

Besides the somewhat hidden Lorentz-covariance, this dynamics also has self-evident Galilean covariance. The number c is absent entirely. Relativity's ubiquitous $(1 - v^2/c^2)^{1/2}$ factors are after all non-unique. There is no adjustability whatever of "masses" or "interaction strengths"—the numerical factors $\pm 1/2$ cannot be touched without totally harming Lorentz covariance. Additionally, there is invariance to space and to time reflections and to scale changes in coordinate and in time. There is so much symmetry that the dynamics nearly fails to exist.

It is easy to see that, simply because c is not around for velocities to com-

pare themselves with, not only are superlight velocities possible, but they are mandatory, and the transition from the sub- to superlight velocities and back again is not marvelous. The motion is in fact just (using a principal value integration through $x_1 = x_2$)

$$\begin{matrix} x_1 \\ x_2 \end{matrix} = a + bt \pm |\alpha t + \beta|^{1/2}$$

being parabolas in the x, t plane. The figure shows a plot of $t \pm |t|^{1/2}$. Around the "collision point" $t = 0$ the motion is arbitrarily fast. The Lorentz covariance stands out sharply now: Parabolas go into parabolas under any nonsingular linear transformation in x and t : the general linear group, including the Lorentz group merely as a special case, is the invariance group of the dynamics.

Given a basically Newtonian structure of dynamics, be it Lorentz-covariant or otherwise, the question of causality comes out to be an empty one. Simply, the motion unfolds, either forwards or backwards in time, from initial data on positions and velocities. The old Newtonian world view does have relativistic survival. The sending and receiving of "signals" is not in the picture. They are not needed. Observability is something else. In the relativistic Newtonian dynamics, unlike the Galilean, forces are not superposable (the sum of two relativistic forces is not a relativistic force). So when observation apparatus (this could be one particle) is brought in, the total dynamics of particle world-lines and apparatus world-lines (the latter not necessarily simple or gently coupled to the former), has to be surveyed somehow all the way down to what is recorded in the apparatus.

Well, concerning the example, isn't that just a toy? No doubt. But the machinery that could produce it would seem to bear study.³ Perhaps, in the machinery's close concentration directly on ensembles of world-lines and their rules of construction, some wider view of relativistic nature is possible. On this view, for instance, preoccupation with momentum-energy four-vectors of the usual type is fruitless. The generalization to *system* momentum-energy, which has the interaction wound up in it, becomes more central.

There is of course a specially pointed reason for attempting the Newtonian view besides mind-broad-

HELIUM

in the purities you need...

packaged for greatest convenience

Grade 4.5™ 99.995% minimum
Grade 5™ 99.999% minimum
Grade 5.5™ 99.9995% minimum
Grade 6™ 99.9999% minimum

Airco Helium is available in a variety of cylinder and flask sizes for your convenience. Helium and other high-purity gases are described in Airco's new *Rare and Specialty Gases Catalog*, the most complete of its kind. Gases, mixtures, and equipment for every application. For a copy of our new catalog, write: Airco Rare and Specialty Gases, 575 Mountain Avenue, Murray Hill, N.J. 07974.



AIRCO
Industrial Gases



SUPERCON INTRODUCES A NEW HIGH WIRE ACT.

Research balloons like this have been performing chemical and energy analysis of cosmic rays at altitudes over 20 miles. Sounds like Buck Rogers stuff, but it's been made possible by new lightweight superconducting magnets that haven't the size and weight limitations of conventional magnets and power supplies.

SUPERCON superconducting material is a key factor in the light weight and smaller size of these magnets. This one for example, was built by Super Magnetics of Concord, California with SUPERCON 30 mil diameter type G wire. This magnet achieved a field of 10 kG in a one foot diameter bore (55kG at the winding) with a current of 150 amperes. That's essentially short sample

performance, too. For obvious reasons, similar magnets are planned for the first space stations. SUPERCON also makes dependable, economic superconductive material for other, down-to-earth uses. It's available in a wide variety of single and

multifilament compositions for all current and field applications up to 80 kG. For more information, contact: SUPERCON Division, Norton Company, 9 Erie Drive, Natick, Massachusetts 01760, or call Dr. James Wong at 617-655-0500.

NORTON *SUPERCON DIVISION*

ening. What quantum theory we think we understand places the time in a Newtonian role. To begin with, dynamical considerations on the same basis—while still holding to Lorentz-covariance—may show a path to putting $\hbar$ and c together consistently.

There is a final puzzle inside the toy. If we make Hamiltonian clothing for the dynamics with a view to quantization, it can be arranged for either Lorentz or Galilean transformations to be canonical transformations, so that in equivalent Lorentz frames, or else in equivalent Galilean frames, calculations are carried out equivalently. Classical calculations in the end will be indifferent to whether Lorentzian or Galilean viewpoints are taken—the motion is the motion is the motion. But quantal calculations will differ, owing to quite different meanings of canonical variables in the two cases, and to structurally different Hamiltonians. The same physical problem looks really very different through Lorentzian as compared to Galilean lenses. Both being allowed equally, which is “correct,” and why?

References

1. D. G. Currie, *Phys. Rev.* **142**, 817 (1966); R. N. Hill, *Bull. Am. Phys. Soc.* **11**, 96 (1966); *J. Math. Phys.* **8**, 201 (1967).
2. E. H. Kerner, *Phys. Rev. Lett.* **16**, 667 (1966); D. G. Currie, T. F. Jordan, *Phys. Rev. Lett.* **16**, 1210 (1966). The whole family of one-dimensional forces has been uncovered by R. N. Hill (submitted for publication).
3. R. N. Hill, *J. Math. Phys.* **8**, 1756 (1967); E. H. Kerner, *J. Math. Phys.* **9**, 222 (1968). By contrast to the instantaneous action-at-a-distance approach, see H. Van Dam, E. P. Wigner, *Phys. Rev.* **138**, B1576 (1965) and **142**, 838 (1966) for manifestly covariant (but integro-differential) equations of motion.

EDWARD H. KERNER
University of Delaware

It appears that if particles of real mass and separate particles of imaginary mass are postulated, the formalism should be completed by positioning a general complex mass particle of which tachyons and tardyons are but two special cases. Thus, if $m = m_r + im_i$, the requirement that the quantity $E/|m|c^2$ be real necessitates the assumption of a complex velocity, so that $v/c = v_r/c + i v_i/c = \beta_r + i\beta_i$.

Some algebraic manipulation shows that

$$\frac{E}{|m|c^2} = \rho^{-1/2} e^{j(\varphi - \theta/2)}, \quad (1)$$

where

$$\rho = [(1 - \beta_r^2 + \beta_i^2)^2 + 4\beta_i^2\beta_r^2]^{1/2}$$

$$\varphi = \tan^{-1}\Gamma$$

$$\theta = \tan^{-1}\left(-\frac{2\beta_r\beta_i}{1 - \beta_r^2 + \beta_i^2}\right)$$

$$\Gamma = \frac{m_i}{m_r}$$

Thus, equation (1) is real only if

$$\varphi = \frac{\theta}{2} \pm m\pi, \quad m = 1, 2, 3 \dots$$

Neglecting the $m\pi$ term, this gives

$$\frac{\Gamma}{\Gamma^2 - 1} = \frac{\beta_i\beta_r}{1 - \beta_r^2 + \beta_i^2}$$

as the necessary condition for real-particle energy. One may now make a substitution in equation (1) to derive the form of E and to obtain the special cases of superluminal and subluminal particles.

The “acteon” suggested here seems to be only mathematically acceptable unless some plausible interpretation of complex velocity is offered.

G. N. TSANDOULAS
Lincoln Laboratory

In connection with the recent discussion of causality objections against tachyons, the following remarks may clarify matters.

Any physical theory has two ingredients: differential equations of motion and prescriptions of how to impose boundary conditions. Any acceptable theory must be self-consistent. To achieve self-consistency, it is not sufficient to require that the equations of motion have solutions that are single valued. In addition, one also has to require that the boundary conditions be compatible with each other and with the equations of motion.

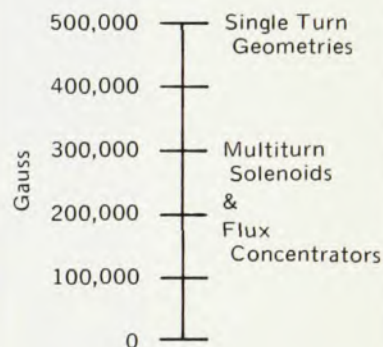
Our conventional physical theories are self-consistent (as far as we know). The equations of motion do have single-valued solutions, and the compatibility of the boundary conditions is ensured by requiring that they satisfy the principle of “retarded causality.”

According to this principle, no effect may precede its cause. In addition to this principle, other causality

PULSED HIGH-FIELD MAGNETS



200 kG Flux Concentrator Magnet
Model HFFC



High Voltage & Electrolytic
Capacitor Banks
High Current Pulse Transformers
Magnets for Room Temperature
& Cryogenic Operation
Field Probes & Peripheral
Electronics

Long Lifetimes
High Repetition Rates
Custom Coil Design for Special
Requirements

ADVANCED KINETICS, INC.
1231 Victoria Street
Costa Mesa, California 92627
(714) 646-7165

A D K I N

STANDARD



EQUIPMENT

We think we make the best analyzers on the market. But we know *any* analyzer . . . once it's in the field . . . is only as good as its maintenance. This is why we have Nuclear Data Service Engineers *specializing* in the maintenance of analyzers. Not *any* analyzer. *Our* analyzers. So when you are in the market for an analyzer, think about the day when it will require maintenance. And think about the Nuclear Data Service Engineer whose services are standard equipment with every analyzer we sell. And think about his ability to service *your* analyzer in *your* laboratory . . . not in our plant. It's food for thought.



1330 E. GOLF ROAD, PALATINE, ILLINOIS 60067 PHONE 312/529-4600 NUCLEAR DATA GMBH, FRANKFURT, GERMANY

principles can also be defined. For example [*Phys. Rev.* **180**, 1266 (1969)], one may define the principle of "advanced causality," according to which no effect can follow its cause, or "full causality," according to which (roughly speaking) an effect may both precede and follow its cause with the same probability.

The important point to notice now is that, while self-consistency is a requirement that all acceptable theories must satisfy, retarded causality is not. In fact, contrary to an often held belief, the more general causality principles do not necessarily lead to self-contradictory theories.

Applying this result to the discussion concerning tachyons, we may conclude: Even if it were true that some interactions involving tachyons could not be explained by any theory satisfying *retarded* causality, that would not necessarily imply that tachyons cannot exist.

Certain causality principles (but not all of them) are physically equivalent. For example, let us assume that time-reversal invariance holds. Then, quite obviously, whenever a series of events can be explained by a theory satisfying retarded causality, the same events can also be explained by a theory that satisfies advanced causality and vice versa. Schematically:

Retarded causality $\iff$ Advanced causality
(If time-reversal invariance holds)

Let us now assume that tachyons do exist, and have the properties ascribed to them in the literature. Then there exists a coordinate frame in which the event of a tachyon emission is described by a theory satisfying retarded causality (for example, in the rest frame of the tachyon emitter). In any other frame, then, this event can be described by a theory satisfying either retarded or advanced causality, depending on whether the Lorentz transformation switches the time direction or not. (Switching can happen if velocities $> c$ can exist.) With time-reversal invariance, it follows from equation 1 that, viewed from any frame, the event can be explained by a theory satisfying retarded causality. (However, two observers in two different frames, both able to explain a sequence of two events, and both using the language of retarded causality, may then disagree about which of

the two events caused the other.) The final conclusion does not depend on the assumption of time-reversal invariance.

In usual physics we easily avoid incompatible boundary conditions, with our eyes closed, so to say, because we have had a great deal of experience with retarded causality.

For example, let us describe a series of events in the coordinate frame K. Let us specify the boundary conditions B_0 (for example, emission of particles) at time $(t_0)_k$ as measured in K. Let the system develop according to certain known equations of motion between $(t_0)_k$ and $(t_1)_k$ (for example, emitted particles travel in vacuum). Let us specify certain additional boundary conditions B_1 at $(t_1)_k$ [for example, particles absorbed by an instrument at $(t_1)_k$] as well as boundary conditions B_2 at $(t_2)_k$ [perhaps, emission of some other particles at $(t_2)_k$]. We may give B_2 in such a manner that they depend on the state of the system at $(t_1)_k$ [for example, if particles are absorbed at $(t_1)_k$, then some other particles are emitted at $(t_2)_k$, but not otherwise]. At times between $(t_2)_k$ and $(t_3)_k$, let the system evolve according to certain known equations of motion, then let us specify boundary conditions B_3 at $(t_3)_k$, and so on.

How can one insure the compatibility of all these boundary conditions B_i ($i = 0, 1, 2, \dots$)? One easy way is to proceed as follows. First, make sure that B_1 is compatible with B_0 and the equations of motion that govern the system between $(t_0)_k$ and $(t_1)_k$. Second, make sure that B_2 is compatible with B_1 and whatever is known about the system between $(t_1)_k$ and $(t_2)_k$ (for example, the workings of the instrument), and so forth. In other words, make sure that B_{i+1} is compatible with B_i and the behavior of the system between $(t_i)_k$ and $(t_{i+1})_k$, for all i . Now it is well known that in this case any B_i will be compatible with any B_j (not just for $t_i = i + 1$), *provided* that the times t_i are chosen so that $(t_i)_k \leq (t_{i+1})_k$ for any i , because if the B_i are compatible over all successive time intervals, then they are compatible over the whole history.

Making sure that any B_i $\iff$ is compatible with B_{i+1}

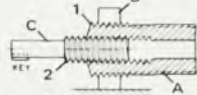
{ Making sure that any B_i (2a)
is compatible with any B_j

This is not a micrometer head

It has a motion 100 times finer than an ordinary micrometer head.

It is a 22.501 Differential Screw Translator. The 22.501 has an equivalent pitch of 4000 t.p.i., and permits controlled mechanical motions as small as 1 millionth of an inch. A companion model, the 22.505, has a motion 20 times finer than an ordinary micrometer head.

How it works



Rotated clockwise, thimble A travels left through fixed nut B. Spindle C, which is keyed and cannot rotate, must move relative to A. The net motion of C results from the difference in pitch of threads 1 and 2.

Convenient mounting shoulder and retaining nut.

Non-rotating, removable tip.

Actual size.

Specifications

Model	Vernier Division (nom.)	Index Division (nom.)	Total Travel	Price
22.505	.000005"	.00005"	.050"	\$79.50
22.501	.000001"	.00001"	.010"	79.50

We will be happy to send you complete information about differential screws. Fill in this form and mail it today — or call us at 607-272-3265.

Lansing Research Corporation, 705 Willow Avenue, Ithaca, New York, 14850. (7)

☐ Please send complete free catalog.

Name

Dept. or MS

Company

Street

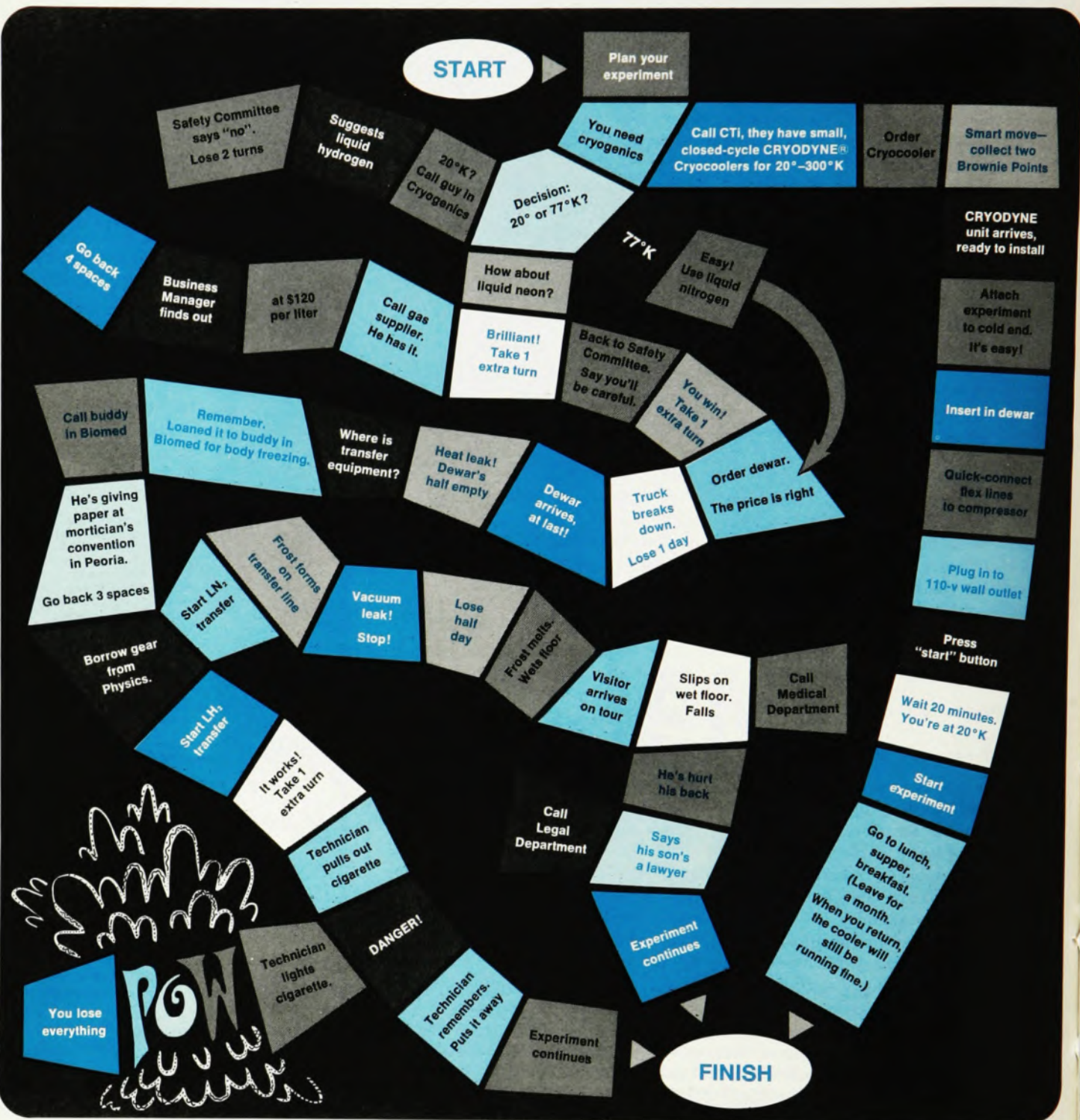
State

City ZIP

Lansing

Play COOL IT

The frustrating cryogenic game for spectroscopists.



Send for details on how you, too, can win at cryogenics with the CRYODYNE[®] Cryocoolers. The Model 20 can operate in the 20° to 300°K range; the Model 70 in the 50° to 300°K range. Both are compact, inexpensive, easy-to-use systems that can give thousands of hours of worry-free service.



CRYOGENIC TECHNOLOGY, inc.
Kelvin Park, 266 Second Avenue, Waltham, Mass. 02154

whenever $(t_i)_{k_i} \leq (t_{i+1})_{k_i}$ for any i
(2b)

and all K_i are the same (2c)

As an illustration, consider the following. The B_0 means the appearance of monoenergetic protons at the point x at $(t_0)_k$, all of the protons travel in vacuum until they hit a counter at point y at $(t_1)_k$, at $(t_2)_k$ protons with the same energy are emitted at point y whenever protons hit the counter at $(t_1)_k$, but not otherwise, and, finally the protons travel in vacuum until at $(t_3)_k$ they reach point x . This is a perfectly consistent way of specifying boundary conditions in usual physics, provided that all $(t_i)_k \leq (t_{i+1})_k$. If, however, this condition is violated, for example, if $(t_2)_k > (t_3)_k$, then the above set of boundary conditions are no longer necessarily all compatible with each other. In particular, if $t_3 = t_0$, then they are certainly incompatible, because B_0 states that at x all protons travel towards y , at t_0 , while B_3 states that they travel in the opposite direction at $t_3 = t_0$.

Equation 2 can immediately be generalized, remembering that whenever all signals and coordinate frames travel with velocities less than c with respect to each other, the time order of any causally connected two events is not interchanged by Lorentz transformations: if $(t_i)_k \leq (t_{i+1})_k$ then $(t_i)_{k'} \leq (t_{i+1})_{k'}$, where K and K' are any two rest frames of observers or particles. In other words, if none of the velocities is superluminal, then condition 2c can be dropped, and the frames K_i may be all different; 2b alone will insure that 2a holds.

It is important to keep in mind that 2a can not be dropped in general if some particles have superluminal velocities. This is so, because then it may happen that $(t_i)_k \leq (t_{i+1})_k$ but $(t_i)_{k'} > (t_{i+1})_{k'}$ if K and K' are two suitably chosen frames, even if the events at t_i and t_{i+1} are causally connected. Therefore, the usual procedures of specifying boundary conditions do not guarantee that these conditions are all compatible with each other, unless condition 2c is valid. An analysis of the unusual paradoxes quoted in connection with tachyons shows that all of them arise because the boundary conditions were given in various frames in a manner that satisfies condition 2b, but in violation of 2c. That such a procedure does not

lead to a self-consistent solution, that is, that condition 2a is not valid, is, in view of what was said above, not surprising. However, while these paradoxes do not at all demonstrate the logical inconsistency of a theory that permits the existence of tachyons, they do clearly illustrate that boundary conditions have to be given with care.

Independently of whether tachyons exist, the principle of retarded causality may prove to be too narrow to describe nature on the deepest level. The possibility in a more general theory (based on full causality) of defining and discussing the "velocity of time," the possibility of closing causal chains, and of changing the singularity structure of scattering amplitudes, to mention just a few, appear to indicate this. During the last century many geometers believed that Euclidean geometry was the only logically possible one. Today more general geometries are widely accepted. I believe that, quite similarly, retarded causality, which is almost universally believed today, will prove to have been merely a hangup with which many of us were afflicted, and that the time is not far away when a more general causality will be accepted as a matter of course. Then many will no longer know that the more general causality principles were not always around, and few will remember where they came from. People will probably say: "Full causality? Why not? Violation retarded causality? Who cares?"—And they will be right.

PAUL L. CSOKA
University of Oregon

In their rebuttal (December, 1969) of several letters concerning their article on tachyons, Bilaniuk and Sudarshan represent the point of my paper (Phys. Rev. 163, 1274, 1967) as "So what?" in reaction to the causality objections. That entirely misses its intention. Rather than trying to make the argument here in a few lines, I refer the interested reader to my forthcoming article in *Science*.

R. G. NEWTON
Indiana University

The ideal job

What could be more meaningful employment for a new PhD physicist than teaching in our overcrowded colleges? I heartily second this sugges-



Ion implantation in a single package.

We'll install the complete system for you: the source, focusing magnet, high resolution analyzing magnet, beam scanner, substrate holder, and vacuum system. Your choice of high or low energy, Boron or Phosphorus, a variety of more exotic ions, and hardware accessories.

Or you may want to assemble your own system from our catalog of in-stock components. Either way, our 20 years of accelerator experience is bound to prove helpful. To get started, call Mr. Julian Cherubini: 617-272-1313. All inquiries held in strict confidence.

HV HIGH VOLTAGE ENGINEERING
EQUIPMENT DIVISION, Burlington,
Massachusetts 01803