then more power to it! But in fact, positivism, and in particular logical positivism, has had less influence than it deserves. This philosophical school advocates a logical analysis of scientific concepts and the avoidance of meaningless questions. It has helped to clear much metaphysical fog.

Finally, it is amazing to find you deprecating the use of mathematical methods in science. Without this, physics would be impossible, as has been known since the discovery of the laws of strings by Pythagoras. It is true that in some sciences at some periods qualitative methods may be sufficient, as in the case of Darwin. But Darwin was followed by Mendel, and who will deny the mathematical nature of modern genetics? And biophysics and biochemistry, insofar as physics is a component, must eventually be highly mathematical. In sum, science and technology are being used as a convenient scapegoat by those who refuse to see the real causes of the distress of our day.

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The editor comments: There was no intent in the December editorial to deprecate the value of mathematics. There is, of course, an immense advantage in being able to formulate the significant questions in a field of study in mathematical terms. But unfortunately there is too often an overreaction in the form of the attitude that unless a field of study is able to use mathematics it isn't really science. The result has been that frequently people in the "softer" sciences mistakenly try to employ mathematical approaches to problems for which the methods of Darwin would be more appropriate. See the late William Feller's views on this point (Scientific Research **4**, No. 3 24 (3 February 1969)).

How Neptune was discovered

For the sake of historical accuracy I would like to correct two minor points in the excellent article by John S. Rigden ("Reshaping the Image of Physics," October, page 48).

The English mathematician John Adams who calculated the location of Neptune prior to its discovery was not an undergraduate at the time he worked on this problem. Having already graduated at Cambridge as Senior Wrangler in 1843, he commenced work on the Uranus problem (part time!) arriving at his first results in 1845.

The often-referred-to "small discrepancy" that Bouvard noticed in Uranus's position was, in fact, substantial if measured against what was then detectable. In 1820 the error in Uranus's position was about 21 seconds of arc, which is approximately an order of magnitude larger than other effects that had been observed (such as stellar aberration and stellar parallax).

Indeed, the full story of the discovery of Neptune is one of the most dynamic and human stories in the entire history of physics. It is a shame that time has buried this tale so deeply. Congratulations to Rigden for giving it a moment's breath out in the open.

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What is modern physics?

Your March issue, devoted to physics for the nonscience major, carried a review (page 75) in which my recently published college text, *Introductory Physics, a Model Approach,* was compared with Leon Cooper's very excellent *An Introduction to the Meaning and Structure of Physics.* I should like to question reviewer Thomas Von Foerster's unspoken assumptions as revealed in his comments about my "slight" treatment of modern physics and his suggestion that my book was better suited to high-school courses.

▶ What is "modern physics"? Most authors and the reviewer appear to consider relativity, quantum theory, subnuclear particles, and symmetry principles to be essential ingredients of modern physics. While I agree that these are the important topics in current research, it is also a sad fact that their very abstract nature—the remoteness of their models from common experience—makes them exceedingly difficult for laymen to grasp. I have therefore looked beyond these specific areas and propose that operationalism, together with the awareness that models are not truth, characterizes 20th-century physics in a deeper way than relativity.

▶ What distinguishes "high-school" from "college" physics for nonscience students who avoided taking physics in high school because of disinterest, fear, or lack of time? The students are in college and have never had physics before. Should they ". . . stand, perhaps in awe, before the 'cathedral-like' structure of physics," as Von Foerster expects from Cooper's text? Or is it better that they ". . . feel at home in the structure of physics," as Von Foerster describes the aim of my book? Both of these objectives are undoubtedly worthwhile, but, "feeling at home" would seem to come before "standing in awe" if students are to understand rather than merely being impressed. This is especially true for the many students—50% in some of my classes—who hold an active hostility toward science because its technological applications can so easily be used for evil purposes. A

University of North Carolina student, in a class using my book, put it this way: "The book fits comfortably into the growing trend of linking science to the humanities. The basic criticism I forsee is that the book is a bit too trivial for first-year college students. The critics will perhaps believe the book to be of more benefit on the high-school level. I would not agree with the latter point."

In anticipation of Von Foerster's call for "padding" to make my text usable in a full-year course. I have prepared an accompanying collection of articles, including contributions by Arthur Koestler, John Maynard Keynes, Merle Tuve, Jean Piaget, *physics today* editor Harold Davis, I. I. Rabi, Roger Bannister, Robert Oppenheimer and Edward Teller, among others.

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Fresnel and the tachyon

In connection with the recent wide interest in tachyons (May, 1970, page 13) readers of *physics today* might like to have their attention called to a case where it seems that tachyons are quite close at hand.

What one does with an imaginary proper mass, one does just as well with an imaginary component of the momentum. Fresnel's evanescent wave in total reflection is formally a plane wave with a complex propagation vector **k,** having (in units such that $c = 1$ and $\hbar = 1$, and ω denoting the angular frequency) components $k_x > \omega$, $k_y = i\,(k_x^2 - 1)^{1/2}$, $k_z = 0$. That *lichtquanta* associated with such a wave will behave, in some essential respects, like tachyons is easily demonstrated. It is well known that the imaginary part k_y of the phase contributes in fact to the amplitude of the wave. Of course the corresponding real exponential factor can be expanded as an ordinary Fourier integral; the point is however that conservation of the energy-momentum with ω and k_x fixed forbids any of these Fourier components to be separately absorbed or emitted; only the whole phase-coherent Fourier integral, that is, the imaginary quantum k_y, can be absorbed or emitted.

Then it is easily verified[1] that if, say, an ion beam is sent in the evanescent wave parallel to x with exactly the appropriate velocity, it will simultaneously absorb an energy quantum ω and a momentum quantum $k_x > \omega$ by going from one eigenstate to the other, and that the transition amplitude will be proportional to the product of the x, y, z expressions of the amplitude of the ionic wave and of the evanescent electromagnetic wave. An experiment is presently planned along these lines.

Finally we come to the question of the group velocity. It is well known that for deriving a group-velocity formula one needs a stationary phase argument *plus* another constraint. With tachyons proper, using de Broglie's constraint that the proper mass is dispersionless, one obtains a spacelike group four-velocity collinear with the four-momentum. With our tachyon photons we have dispersions $\delta\omega$ and δk_x, and we have to impose a correlation between them. Choosing $\delta[(n^2\alpha^2 - 1)^{1/2}\,\omega] = 0$ where, n denoting the index of the refracting medium and α the sine of the incidence angle inside it, $k_x = \eta\alpha\omega > \omega$, that is distributing our tachyon-photons with respect to their penetration depths, we obtain $\omega\delta\omega - k_x\delta k_x = 0$, which together with $\delta d\phi \equiv \delta\omega\, dt - \delta k_x\, dx = 0$ yields $dx/dt = k_x/\omega > 1$—a reasoning and conclusion quite similar[2] to those applicable to tachyons proper. But neither for tachyons proper (if they exist) nor for these tachyon-protons (that should exist) is there ground to believe that a signal velocity could be greater than one.

References

1. O. Costa de Beauregard, Compt. Rend. **270B,** 773 and 1004 (1970).
2. O. Costa de Beauregard, *Précis of Special Relativity,* Academic, N. Y. (1966), page 110. Equation 7 in this work should read $\beta_F \simeq -\eta/n\alpha\omega \simeq \beta_E$, that is, in the form of generalized Doppler effect.
3. Ch. Imbert, Compt. Rend. **269B,** 1227 (1969) and **270B,** 529 (1970); Phys. Lett. **31A,** 337 (1970).
4. F. Goos, H. Hanchen, Ann. Physik l, 133 (1947).

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Still more on tachyons

O. M. Bilaniuk and E. C. Sudarshan have pointed out (May 1969, page 43) that it is very important to make sure that tachyons are consistent not only with relativity theory but also with quantum theory. I would like to comment on this point.

Bilaniuk and Sudarshan have studied the dependence of $E/|m_0|c^2$ versus $P_x/|m_0|c$ (their figure 1). For a given momentum P_x there are therefore always two values of the energy, $+E$ and $-E$. It is just this double sign for the energy that necessitates the use of a four-component wave function in Dirac's wave equation.

With the smallest value of $P_x = 0$ we associate two values of $E_0 = \pm m_0c^2$. The particle can not exist in the region $m_0c^2 > E > -m_0c^2$, because P_x must be

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