relativistic quantum field theories in an explicitly Lorentz-invariant form. In the ruins of Tokyo in the immediate post-World War II period, Tomonaga used this formalism to formulate the renormalizaton procedures, as did Hendrik Kramers, Hans Bethe, Julian Schwinger, Richard Feynman and Freeman Dyson, working on the other side of the world. This made it possible to isolate and discard in a consistent manner the divergences encountered in perturbation-theory calculations of quantum electrodynamics and thus to perform a fully relativistic calculation of the Lamb shift. For this work, Tomonaga shared the Nobel prize with Feynman and Schwinger in 1965.

Nishina died unexpectedly in January 1951, and Tomonaga took over many of his duties on governmental committees. Tomonaga's technical knowledge, sagacity and evenhandedness led inevitably to his being involved almost full-time in science policy. He served on many influential governmental committees, eventually becoming the president of the Science Council, and he was frequently appointed the official emissary to represent Japanese culture and science at international gatherings. He actively participated in the Pugwash Conferences until the end of his life.

Most of his time after 1951 was taken up by administrative duties, including three terms as president of the Tokyo University of Education, and he welcomed his retirement in 1969. It gave him the leisure to give lectures, to write essays on a variety of subjects and to cultivate his friendships. At the time of his death, he had completed a manuscript that was published posthumously in two volumes with the title *What is Physics?*

A threnody from *Man'yoshu*, an anthology of 8th- and 9th-century Japanese poems, expresses the emotion shared by all who came in contact with Tomonaga during his mature years:

If I could believe that there were
Two men like you in Japan,
I would never grieve.

The Nature of Space and Time

Stephen Hawking
and Roger Penrose
Princeton U. P., Princeton, N.J., 1996. 152 pp. $24.95 hc
ISBN 0-691-03791-4

The clash between Niels Bohr and Albert Einstein over the meaning of quantum theory greatly clarified some fundamental issues, but to this day it is widely felt that their differences have never been satisfactorily resolved. It seems most appropriate, then, for two leading physicists of the current era to carry on the debate, and who could be better qualified than Stephen Hawking and Roger Penrose? Arguably, the two most profound developments in general relativity since Einstein were the introduction of the global analysis of causal structure by Penrose and the discovery of black-hole thermodynamics and black-hole radiance by Hawking. Furthermore, both men are justly admired for the lucidity of their writings and lectures, and they disagree sharply on some fundamental questions.

The Nature of Space and Time is based on a Hawking–Penrose debate that took place in England, at the University of Cambridge, in the spring of 1994; the "debate" consisted of alternating lectures (three by each author) followed by a final joint discussion. The lectures revealed that there is much on which Hawking and Penrose agree. Both believe that black holes destroy information and hence undermine the foundations of quantum theory. Both argue that the origin of the second law of thermodynamics can be traced back to the extremely homogeneous conditions that reigned in the very early universe and that it is ultimately the task of quantum gravity to explain these initial conditions. They also seem to agree that general relativity, a beautiful and highly successful fundamental theory, sometimes fails to get the respect it deserves from the particle physicists.

Various points of disagreement are mentioned at least in passing. Hawking advocates the Euclidean path-integral approach to the fundamental issues of quantum gravity; Penrose is skeptical. Hawking offers the "no-boundary proposal" (rooted in the Euclidean formalism) to account for the initial conditions in the Big Bang; Penrose prefers the more phenomenological Weyl-curvature hypothesis. Hawking believes that the universe must be closed (as seems to be required by the no-boundary proposal); Penrose favors an open universe (which meshes more easily with his idea that quantum gravity should be formulated in terms of "twistors"). Hawking is an enthusiast of the inflationary-universe; Penrose is not.

There are two important issues over which the disagreements are more profound and more interesting. First, there is disagreement about the time-reversal invariance (or more precisely, *CPT* invariance) of the microscopic laws of nature. Hawking has a strong conviction that *CPT* is an inviolable symmetry. But Penrose believes that the quantum behavior of black holes shows otherwise; he argues that the laws of quantum gravity must make a fundamental distinction between past and future singularities. Further, they disagree about the measurement problem of quantum theory: Penrose insists that there must be a genuine physical mechanism underlying the "reduction of the state vector" in the measurement process, and he further proposes that quantum gravity plays an essential role in this reduction; Hawking rejects these ideas.

These are certainly fascinating questions, so it is rather disappointing that the authors do not flesh out their positions more fully. To understand Penrose's views clearly, I needed to reread his previous books, especially chapters 6–8 of *The Emperor's New Mind* (Oxford U. P., 1989) and chapter 6 of *Shadows of the Mind* (Oxford U. P., 1994). The key problem repeatedly stressed by Penrose in *The Nature of Space and Time* is that we never perceive macroscopic superpositions—the famous conundrum of Schrödinger's cat. This emphasis surprises me. While the modern theory of decoherence is surely incomplete—it is largely based on heuristic arguments and oversimplified models—I think that there is a plausible explanation, within conventional quantum theory, for the fact that superpositions of macroscopically distinct states decohere very rapidly. (See, for example, Wojciech H. Zurek's article in PHYSICS TODAY, Oct. 1991, p. 36.) Penrose thinks otherwise. There may be other more serious objections to the foundations of quantum theory, some of which are mentioned in Penrose's other books, but these receive scant attention here. Hawking, for his part, defends the status quo, but in so sketchy a manner as to provide little guidance for the perplexed.

I should not give the impression that this is a book about the measurement problem in quantum theory; the lectures largely address other issues: Hawking's three lectures concern global methods and singularity theorems; quantum black holes and information loss; and quantum cosmology, inflation and the origin of the anisotropy of the cosmic background radiation. These lectures are unapologetically mathematical, at an appropriate level for a graduate student in theoretical physics but quite beyond the grasp of the typical lay reader. Penrose's lectures on cosmic censorship, the measurement problem and twistors are less demanding than Hawking's (and about half as long), but they are also intended for a mathematically sophisticated audience. Advanced students and even some experts will appreciate, for example, Hawking's succinct summary of the ideas underlying the singularity theorems or Penrose's overview of the ideas motivating the twistor program.

There is much to savor in this slim volume, but as a dialogue on fundamental issues in quantum theory, it falls well short of expectations. A reader seeking an exposition of Penrose's unconventional views will do better to read his other books. For a well-presented defense of the conventional wisdom, I would recommend *The Interpretation of Quantum Mechanics* by Roland Omnès (Princeton U. P., 1994). Still, we should appreciate this little book for what it is—a succinct and clear technical account of the penetrating work and thought of two of our most brilliant and eloquent scientists.

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Stretch, Twist, Fold: The Fast Dynamo

Stephen Childress
and Andrew D. Gilbert
Springer-Verlag, New York, 1995.
406 pp. $68.00 hc
ISBN 3-540-60258-5

The Earth, stars and galaxies have magnetic fields. More generally, the observation is that naturally occurring, flowing, electrically conducting fluids (an ionized gas in the case of stars and galaxies or a liquid core in the case of planets) are accompanied by magnetic fields. A natural question is why. This question is the subject of *Stretch, Twist, Fold: The Fast Dynamo* by Stephen Childress and Andrew Gilbert. The book is particularly timely because a recent conceptual realization has led to fundamental new understanding. Amazingly, this realization turns out to be that chaos provides the key to the problem. The emerging new picture, to which the authors' own research has significantly contributed, is coherently and lucidly presented in this book.

The question of why naturally occurring, flowing, electrically conducting fluids invariably create their own magnetic fields is addressed by consideration of the so-called kinematic dynamo problem: Given a prescribed fluid velocity $\mathbf{v}(\mathbf{x}, t)$, will a small seed magnetic field tend to grow exponentially in time? The answer, in principle, depends on the exact flow and the electrical conductivity of the fluid. If the answer is yes, one can conclude that a magnetic field will be generated.

What does chaos theory have to do with this problem? The answer is provided by a simple fact: In a very highly conducting fluid, to a good approxima-