The Nature of Space and Time

by Stephen Hawking and Roger Penrose

Reviewed by John Preskill

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The clash between Niels Bohr and Albert Einstein over the meaning of quantum theory greatly clarified some fundamental issues, but many physicists feel 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 authors 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 the spring of 1994; the "debate" really consists of alternating lectures (three by each author) followed by a final joint discussion.

In fact, the lectures reveal that there is much that Hawking and Penrose agree on. 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.

There are various points of disagreement that 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 scenario; Penrose is not.

There are two important issues over which the disagreements are more profound and more interesting. First, they disagree 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. Second, they disagree about the "measurement problem" of quantum theory. Penrose insists that there must be a genuine physical mechanism underlying the "reduction of the wavepacket" 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* and chapter 6 of *Shadows of the Mind*. 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 of why superpositions of macroscopically distinct states decohere very rapidly. (See, for example, W. Zurek in Physics Today, Oct. 1991, p. 36-44.) 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 (1) global methods and singularity theorems, (2) quantum black holes and information loss, and (3) 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 (1) cosmic censorship, (2) the measurement problem, and (3) twistors, are less demanding than Hawking's (and about half as long), but are also intended for a mathematically sophisticated audience. Advanced students and even some experts will appreciate, say, Hawking's succinct summary of the ideas underlying the singularity theorems, or Penrose's overview of the ideas motivating the twistor program.

While there is much to savor in this slim volume, as a debate 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 by reading his other books. For an well-presented defense of the conventional wisdom, I would recommend *The Interpretation of Quantum Mechanics* by Roland Omnès. 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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