

## Book Review

**Time: Towards a Consistent Theory.** C. K. Raju. Kluwer Academic Publishers, Dordrecht, The Netherlands, 1994, xi + 259 pp., \$118.50 (hardcover). ISBN 0-7923-3103-6.

Heightened interest in time in the past few years seems to have been caused by the concurrent emergence of foundational problems involving time in several fields. They are easily enumerated. First, experimental investigations of the predictions of Bell's theorem have shown beyond a reasonable doubt that "nonlocality" (instantaneous conveyance of information over arbitrarily large distances) is an ineluctable feature of quantum mechanics. This counterintuitive result has spurred experimentation wherein "delayed choice" protocols are used, yielding results where the future seemingly affects present and past events.

Second, serious investigations of general relativity theory have revealed that time travel, in principle at least, may be possible. For this to make sense, one must accept the flowless time, the "block universe," of relativistic spacetime. This conflicts with cherished notions of Copenhagen quantum mechanics. Third, the role of time in quantum cosmology and quantum gravity seems to be central: Manipulation of the concept permits the realization of certain aesthetically pleasing boundary propositions. Fourth, the "direction" of the "arrow" of time—why we remember the past, but not the future, despite the time reversal invariance of our fundamental laws—remains as contentious now as it was the better part of a century ago. Arguments from thermodynamics and cosmology in this connection remain less than convincing. And fifth, the origin and relativity of inertia—Mach's principle—suggests that the relativistic understanding of time as a coordinate, not an unfolding process, is the correct one.

While what we remember, the arrow of time, quantum cosmology, and quantum gravity, are all fascinating subjects, they are arguably not the fundamental problem of time. That problem, as Einstein insisted more than sixty years ago, is: How do we reconcile instantaneous action with local

Lorentz invariance? Writing relativistically invariant wave equations (*à la* Klein-Gordon and Dirac) is not enough. Quantum “entanglement” renders those equations effectively moot in this business. It is a pleasure to find that C. K. Raju understands that many of the topics mixed into most discussions of time are really red herrings—and in his book he takes the trouble to explain why. Resolution of the fundamental problem is the chief focus of his book. It is a book that I hope you will enjoy reading as much as I did.

Although much of this book was first published in a series of articles in *Physics Education* (India), it is not a book for the formally faint-hearted. But anyone with a strong physics background should not encounter serious difficulties. Raju’s treatment of the subject is comprehensive. Indeed, he includes several interesting digressions that are, at best, tangential to his main theme. As stated in his title, that theme is to find a “consistent” theory of time. By “consistent” he means a theory that is compatible with relativity theory, quantum mechanics, and our ordinary sense of everyday, in his idiom “mundane,” time. The prescription Raju advocates to achieve this goal is the abandonment of the concept of causality, at least at the level of microphysical phenomena; that is, rejection of the assumption that microphysical events are determined only by antecedent events.

Raju writes with ease and deft wit (which graces too little technical literature these days). For example, in addressing the distinction between chance and choice, notions easily confounded if one is not paying attention, he notes that indeterminism in the Copenhagen interpretation of quantum mechanics, contrary to what one might think, does not necessarily make “free will” possible:

...Consider a slot machine which delivers either ice-cream or chocolates in a way that is in principle completely unpredictable. By assumption, what one eats is a matter of chance, but does one have a choice?

In practice, one could perhaps go on putting coins in the machine until it delivers the item one wants. But this is fallacious. The choice available, in practice, exists only with the mundane picture of time! [Mundane time is that of our everyday experience.]

A more accurate picture of the world, according to the Copenhagen interpretation, is provided by a giant machine which slams one down in front of either ice cream or chocolates, and rams one of these down one’s throat. What one eats becomes a matter of chance, but one has no choice in the matter.

This book is too rich and robust to admit a simple, comprehensive synopsis. Raju’s core argument, however, can be briefly recapitulated. After examining Newtonian time, relativity, thermodynamics, and the like, he discusses the creation of field theory in the 19th century. Invented by Faraday as a means of avoiding Newtonian action-at-a-distance, it allowed physicists, seemingly at least, to rid electrodynamics of instantaneous,