The Foundational Aspects of Quantum Mechanics Made Accessible to Everyman (or Everyphysicist)

Conceptual Foundations of Quantum Physics: An Overview from Modern Perspectives

Dipankar Home
Plenum, New York, 1997. 386 pp. $115.00 hc ISBN 0-306-45660-5

Reviewed by James T. Cushing

Dipankar Home has for many years been actively involved in research on foundational issues in quantum mechanics. As the title of his book indicates, he has written an overview of an aspect of modern physics that until fairly recently has been too little appreciated by the physics community as a whole. Today, however, both philosophers of physics and practicing theoretical and experimental physicists are at least receptive to research on the foundational aspects of our most successful scientific theory to date: quantum mechanics.

Conceptual Foundations of Quantum Physics represents a novel attempt at introducing this growing corpus of work to a wider audience of scientists. Although the author is concerned with basic conceptual matters, he keeps the discussion anchored in quantitative physical phenomena and empirical implications. Results previously published by Home and his coworkers are heavily represented in the technical topics covered. Still, Home does discuss most of the central problems in the foundations of quantum theory.

In presenting the standard conundrums associated with the measurement problem, the classical limit of quantum mechanics, quantum nonlocality, complementarity, decoherence and causality in quantum theory, Home continually returns to a central theme: attempts to choose among various versions or interpretations of quantum mechanics (for example, the standard or Copenhagen formulation, the statistical interpretation, David Bohm's theory and spontaneous reduction models). One of the strengths of his approach is that it keeps in focus the empirical and conceptual importance of the ontology (essentially, the story or picture of the furniture of the world) that goes with the equations and calculational rules that occupy much of the time and energy of a professional physicist.

This monograph assumes that one has a solid background in the theory and mathematics of quantum mechanics. So the intended reader is really the professional physicist who is not already an expert in this field and wants an introduction both to some of the major outstanding theoretical and conceptual problems in quantum theory and to related proposed experiments. For such a person, Home provides what could be a stimulus for further reading in this important area of research.

Even though the level of presentation of the physics is at times quite detailed and technically advanced, there are also excursions into certain historical and philosophical matters. However, the latter consist mainly of brief selected quotations (from Albert Einstein, Niels Bohr, Werner Heisenberg and the like), rather than conceptual analyses such as those one would find in the professional literature of the history and philosophy of science.

Although Home does present several points of view, along with their strengths and weaknesses, overall he comes down, it seems to me, in favor of David Bohm's formulation of quantum mechanics. The basic reason is that this theory, while being empirically equivalent to the standard version, provides an objective (observer-independent) reality based on an ontology of entities and properties actually existing at all times. Related to this, in section 5.6, one finds a clear illustration of a major conceptual difference between the views of Louis de Broglie and Bohm on an important aspect of such an objective ontology underlying quantum phenomena.

Let me put my own gloss on this point: One often sees the expression "the de Broglie–Bohm theory" in the foundations literature. This is good, in that it does at least indirectly refer to the fact that as early as 1927, de Broglie, in his pilot-wave theory, did have in its essentials the theory that Bohm would (apparently independently) discover in 1952. However, this attempt to apportion priority equitably can obfuscate an important central debate: locality versus nonlocality in quantum theory.

The de Broglie–Bohm theory is inherently nonlocal (although its nonlocality produces no empirical conflict with the special theory of relativity), but de Broglie's first love, as it were, his theory of the double solution, is basically a local theory (with waves in physical three-dimensional space only, as opposed to the multidimensional configuration space of Bohm). The resurrections after 1952 of de Broglie's ideas, to which de Broglie himself contributed, were firmly rooted in this "local" approach (in spite of Bell's subsequent theorem and apparent empirical difficulties).

Hopefully, Home's book will contribute to increased interest, among scientists, in the meaning and implications of quantum theory.

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Time's Arrows and Quantum Measurement

Lawrence S. Schulman
Cambridge U.P., New York, 1997. 346 pp. $90.00 hc ($25.95 pb) ISBN 0-521-56122-1 hc (0-521-56775-0 pb)

Time's Arrows Today: Recent Physical and Philosophical Work on the Direction of Time

Edited by Steven F. Savitt
Cambridge U. P., New York, 1997. 330 pp. $24.95 pb ISBN 0-521-59945-8

The two books being reviewed here are part of a steady (or quasi-periodic) stream of books and articles having the phrase "time's arrow" in their title. In June of last year I reviewed in these pages (page 68) Huw Price's book, *Time's Arrow and Archimedes' Point* (Oxford, 1996) and, perhaps not completely coincidentally, I am also the author of such an article: "Boltzmann's Entropy and Time's Arrow" (PHYSICS TODAY, September 1993, page 32).

These writings differ greatly in their starting points, lengths, ambitions and conclusions. Many people (at least those I can understand) accept provisionally Newton's absolute time, which "of itself, and from its own nature, flows equally without relation to anything external," as a primitive, undefined notion, and they don't worry much about the changes in the notion of time introduced by relativity. They focus instead on the conflict between the time's arrow as a physical phenomenon, which has (or at least seems to have) a definite direction in time, and the fact that the successful basic theories of physics, ultimately derived from and pertaining to the same phenomena as the arrows, have a time-reversal invariance. There are many time's arrows (Roger Penrose, in a 1979 article called "Singularities and Time-Asymmetry," in *General Relativity: An Einstein Centenary*, S. W. Hawking and W. Israel, eds. (Cambridge U. P., 1979), listed seven) but the time-asymmetric, entropy-increasing behavior of macroscopic objects is generally acknowledged to be a central one.

The explanation of this apparent paradox from Boltzmann to the present involves (among other things) the fact that events are determined not only by the basic laws but also by initial conditions, indeed by the way our universe started some 10 or 15 billion years ago, according to present cosmological ideas. While this seems quite satisfactory to me, most of the authors in these books are unhappy with it, albeit for reasons more philosophical than physical. In particular, some argue (with reason) that the appeal to initial conditions is itself time-asymmetric and that it is more natural to consider both initial and final conditions. This was the central theme of Price's book and constitutes a substantial part of both Lawrence Schulman's *Time's Arrows and Quantum Measurement* and *Time's Arrows Today* edited by Steven Savitt (a corrected, softcover edition of a 1995 book).

A completely different response to the problems posed by time's arrow is to include asymmetry in the basic laws. A particularly tempting place to do this is in the "measurement equals wave function collapse" version of the Copenhagen interpretation of quantum mechanics. This is, however, not the point of view taken in these two books. While the quantum measurement problem is very much discussed in both books, most of the authors in the Savitt book who consider this issue seem to agree that the time's arrow in the QMP is part of the time's arrow already present in irreversible macroscopic phenomena, rather than a true time asymmetry at a basic level. As Anthony Leggett, one of Savitt's authors, emphasizes, however, this aspect of the QMP deserves further theoretical and experimental investigation. (For an illuminating discussion of the QMP, independent of time's arrow considerations, see the articles by Sheldon Goldstein in the March and April 1998 issues of PHYSICS TODAY.)

Schulman has a very different view about the whole QMP. His book is based on his work (mostly solitary) over the past two decades, which began with a very radical proposal for resolving the QMP. He suggested that the Schrödinger wavefunction resulting, via the usual unitary evolution, from interactions that might correspond to measurements on a macroscopic system—like a cloud chamber particle detector or Schrödinger's cat—is not, as usually assumed, a wavefunction that is a superposition of incompatible macroscopic quantum states. Rather, it is always a quantum state representing just one of the possible outcomes of such a measurement. Thus, for the Schrödinger cat experiment, in which the usual computations give

$$\Psi = \sqrt{\alpha}\,\Psi_{\text{alive}} + \sqrt{(1-\alpha)}\;\Psi_{\text{dead}}$$

with $\alpha \simeq 1/2$, Schulman claims that α is invariably (for all practical purposes) either 0 or 1.

To make this possible, Schulman invoked the existence of rare special states: wavefunctions of macroscopic systems with just the properties required for such a definite outcome. Schulman exhibited the existence of such special states in some simple models and gave reasons for believing that they exist also for general macroscopic systems. Very roughly speaking, the α for the special states contains a factor like $\sin^2(\pi T/2)$, where T refers, in proper units, to some interaction time involved in the experiment. Now if T is an integer, then indeed we don't get any superposition.

But why should the state of the experimental apparatus prior to the measurement always be special and T always an integer? Schulman's answer is that "in doing an experiment it is impossible to control its precise microscopic state. You set up a macroscopic situation, but the microscopic state of the system will be one of those that avoids superpositions of macroscopically different states in the course of its subsequent time evolution." Going further, Schulman states, "there is a single wave function for the entire universe. This wave function has the precise correlations necessary to guarantee 'special' states at every juncture where they are needed." In particular, the choices that an experimentalist makes about the knob he or she turns is very strongly correlated with the wavefunction of an incoming particle on which a measurement is to be made.

Later, Schulman proposed making his scheme more plausible by combining it with the use of both initial and final conditions for the universe. The idea is something like this: There may exist some natural final conditions on the state of the universe that would force the type of correlation necessary to avoid "grotesque" superposition of macroscopic states. Furthermore, these would occur with just the right frequencies to reproduce the standard quantum probabilities.

Schulman has some specific and interesting suggestions on where one might look for other effects of such final conditions—galactic structures, for example. If such effects were to be found (assuming we could recognize them), this would indeed be an amazing discovery, more than justifying Schulman's efforts. How likely is this? Well, it is not impossible, and who am I to insist that Nature is not capable of being weird in this particular way? (I am, however, quite willing to bet heavily against it.) In any case, the book is recommended for the many interesting and amusing things it says about quantum mechanics, nonequilibrium statistical mechanics and, in particular, "two timing" boundary conditions.

Let me now briefly describe Savitt's book. It consists of an informative, historical introduction by the editor, followed by 11 articles by 10 authors. The articles are grouped into four parts: cosmology and time's arrow, with articles by William Unruh and by Huw Price; quantum theory and time's arrow, with articles by Leggett, Philip Stamp, Storrs McCall and Roy Douglas; thermodynamics and time's arrow, with two articles by Lawrence Sklar (the first a reprint) and one by Martin Barrett and Elliott Sober; and time travel and time's arrow, with articles by Paul Horwich and by John Earman.

The articles differ greatly in point of view and quality. Perhaps not surprisingly, I liked the articles by the physicists, Unruh, Leggett and Stamp, best. Of the philosophers' articles, I found Price's and Sklar's most interesting, although I felt that there were some important things that they didn't get right.

The articles by McCall and Douglas

definitely do not assume the Newtonian picture of time. Instead they discuss branched models of spacetime, which are related but not identical to the famous (or notorious) many-world interpretation of the QMP. The Barrett and Sober article did not make much sense to me, and I couldn't make myself read more than the introductions to the articles about time travel, which I found informative.

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Intermediate Physics for Medicine and Biology

Russell K. Hobbie
Springer-Verlag, New York, 1997, 3rd edition. 575 pp. $79.95 hc ISBN 1-56396-458-9

Many physicists are discovering that they are missing a large part of the current excitement in science because they are unfamiliar with biology. When colleagues ask about reader-friendly books that bridge the gap, I recommend three: the third edition of *Molecular Biology of the Cell* by Bruce Alberts *et al* (Garland, 1994), *The Natural Selection of the Chemical Elements* by R. J. P. Williams and J. J. R. Fausto da Silva (Clarendon, 1996), and Russell Hobbie's *Intermediate Physics for Medicine and Biology*. The Alberts book, a collaboration by six biologists, includes tutorials that are especially helpful for physicists. Chemists Williams and Fausto da Silva are expert on the structure and function of living systems. Their very original book uses "a physicist's approach to materials." And Hobbie's book offers a perspective on physicists' use of their expertise in the understanding of living systems.

Hobbie is a professor of physics at the University of Minnesota. His book derives from 25 years of teaching a two-semester physics course for biology and premed majors. But its constituency also includes undergraduate and graduate students in physics, engineering and physiology who want to understand the connection between the biological and physical sciences. For the professional physicist, the book provides a painless way for gaining a comprehensive view of the successes of biological physics and, for those who teach, adding some enjoyable topics and different problems to their courses at all levels.

This edition, published by Springer under the AIP Press imprint, has a larger page format and more readable