The Physics and the Philosophy of the Foundations of Quantum Theory

The Interpretation of Quantum Mechanics

Roland Omnès
Princeton U. P., Princeton, N. J., 1994. 550 pp. $39.50 pb ISBN 0-691-03669-1

Reviewed by Richard Scalettar

Roland Omnès, of the University of Paris, has devoted the last seven years to a formulation of the consistent histories picture of quantum theory, culminating in the present important 550-page monograph. *The Interpretation of Quantum Mechanics* is the first quasi-pedagogical presentation of this subject. It is well written and may usefully serve as a supplement to a standard quantum mechanics text or as the basis for an independent course on the foundations of quantum theory. In the words of Christopher Isham: "Most workers in the field agree that, at the very least, the idea of consistent histories provides valuable insight into the relation between classical and quantum physics."

The starting point for consistent histories methodology is the assignment of a probability to a history (a temporal sequence) of events, specified by von Neumann propositions and their associated projectors. The mathematical form for this probability is exactly that of the Wigner formula. There is, however, an important mathematical and physical distinction: The formula presented by Robert Griffiths in his seminal 1984 paper in the Journal of Statistical Physics, **36**, 219 (1984) applies to closed physical systems (the entire universe!), not to the observed system as in the case of the Wigner formula. Correspondingly, the Hamiltonian, which governs the time evolution of the projectors, is that of the closed system, and no reference is initially made to measurement *per se*.

Now consider a family of histories for the closed system under study. The probability assignment for each history, itself considered an event in the sample space, is required to satisfy the conventional Kolmogorov axioms of probability theory; this leads to a set of consistency conditions, first discovered by Griffiths. Meaningful probabilistic assertions are then restricted, by fiat, to a consistent family of histories. For a given closed system, there are many such consistent families, some of which are, however, incompatible with one another. In this way, Bohrian complementarity is manifested in the consistent histories picture.

A beautiful formal accomplishment of the Omnès treatment is the proof that the satisfaction of the probability consistency conditions entails the applicability of the rules of conventional Boolean logic. A family of consistent histories may thus be thought of as a quantum logic with a universe of discourse whose events are the

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Veiled Reality: An Analysis of Present-Day Quantum Mechanical Concepts

Bernard d'Espagnat
Addison-Wesley, Reading, Mass. 1995. 474 pp. $65.75 hc ISBN 0-201-56988-4

Reviewed by Richard Scalettar

Bernard d'Espagnat has had a long and distinguished career in physics. He has served as director of the Laboratoire de Physique Théorique et Particules Elémentaires in Orsay, France, and is presently an emeritus professor of physics at the University of Paris.

The primary stated purpose of *Veiled Reality* is to make accessible to students of philosophy a precise mathematical formulation of fundamental interpretative problems of quantum theory. However, this work will prove to be very useful to students of physics as well; its central portion is a clear and unique analysis of the standard formulation of quantum mechanics, its interpretational difficulties and the many reformulations that have been proposed for resolving these problems.

It is, perhaps, appropriate to remark, for those who may be put off by philosophical considerations, that many distinguished physicists, past and present, have devoted much effort to obtaining an understanding of the relation between physics and reality. Moreover, as d'Espagnat makes abundantly clear, philosophical assumptions implicitly underlie many of our basic considerations and influence our conclusions, as is illustrated, for example, by his discussion of ontological approaches to quantum theory.

On purely philosophical grounds, d'Espagnat argues that independent reality—that is, reality independent of human observers—does indeed exist. However, in deference to the work-a-day world of the ordinary physicist, he places primary emphasis on empirical reality, the domain of observable phenomena, which are the building blocks of all scientific investigations. Finally, he argues that, while empirical reality provides some indirect insight into the nature of independent reality, a complete picture of the latter is "veiled" from our view and probably always will remain so.

This review will focus on the concept of empirical reality, which is of primary importance for the operationally minded physicist. The analysis presented by d'Espagnat in the final chapters of his work owes a considerable debt to the interpretation of Roland Omnès (see the accompanying review of Omnès's *The Interpretation of Quantum Mechanics*). Omnès argues that in most circumstances, decoherence causes the collective properties of macroscopic objects to obey the laws of classical mechanics. These properties are designated as "facts" by Omnès and are by definition regarded as true. They are, in excellent approximation, compatible with one another and hence may be included in consistent logics, which are designated as "sensible logics." Other properties (in particular those of microscopic systems) that

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individual members of the family. (Unconventional lattice-theoretic "quantum logics", which have been much investigated, do not enter.) All physical reasoning should be carried out according to the usual rules of logical implication; this is an informal statement of the Omnès "universal rule of interpretation," which, one would hope, permits us to dispense with objectionable, handwaving arguments.

As a consequence of the above rules, Omnès succeeds in providing a derivation of the laws of classical mechanics from those of quantum theory, as well as a proof of the measurement postulates that now appear as theorems. These derivations are in principle accompanied by precisely defined error bounds that delimit their domains of applicability. Especially interesting is the status of the reduction postulate, which has been the source of virtually infinite debate. It now appears simply as an extremely convenient computational tool and is generalized to include, at least in principle, the complexities of the measuring apparatus. For ideal measurements, Omnès's result reduces to the Lüders formula.

The physical reason for the onset of classical behavior, as well as effective noninterference in superpositions of macroscopic states, is the extremely efficient and rapid decoherence effect. This phenomenon, which is carefully analyzed by Omnès, arises from the interaction of the collective coordinates of a macroscopic system with a dissipative environment.

The exceptional cases of macroscopic systems with very small dissipation—SQUIDS and quantum optical devices—were first studied by Anthony Leggett in 1980 and have been the object of numerous subsequent theoretical and experimental investigations. They provide illustrations of macroscopic systems that display quantum tunneling and quantum coherence effects. Their existence poses grave difficulties for the usual formulation of quantum theory, which virtually equates the words "macroscopic" and "classical." These examples, as well as a number of others, are analyzed in the final chapters of Omnès's text, where it is shown that they fit neatly into the consistent histories formalism. However, one wishes that a fuller exposition of the technical details had been provided; from a pedagogical point of view, it would have been desirable to provide a few more simple illustrations of the new ideas quite early in the text.

One should be alert to the presence of a fairly large number of misprints in this otherwise very valuable work. (Some of the important philosophical questions arising from the Omnès formulation are discussed in the accompanying review of *Veiled Reality: An Analysis of Present-Day Quantum Mechanical Concepts*, by Bernard d'Espagnat.)

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may be incorporated into all sensible logics without disturbing consistency and that, therein, are logically equivalent to facts, are also designated as true. These definitions of truth satisfy all of the formal requirements of mathematical logic and hence lead to no contradictions. There exist properties that may be added to some sensible logics but not to all; in those logics into which they may be incorporated, they are again equivalent to facts. Such properties clearly have a more limited significance than true properties and are designated as reliable. The failure in the first papers of Robert Griffiths and Omnès to distinguish clearly between true and reliable properties was noted by d'Espagnat and has led to considerable debate among these three authors.

Finally, I mention one further delicate point upon which d'Espagnat and Omnès differ: In addition to the collective observables, which may obey the laws of classical mechanics, there are the internal microscopic degrees of freedom designated as "sensitive properties;" these are clearly very difficult to measure and hence are veiled from view. Whether this is due to human limitations in the construction of the necessarily exceedingly complex measuring devices, as d'Espagnat believes, or is a limitation in principle, as Omnès believes, is not easily resolved. Omnès bases his view on an interesting theorem that purports to demonstrate that the size of the necessary apparatus exceeds by many orders of magnitude the size of the universe. Moreover, such enormous devices, even granting their existence, would clearly require for their understanding that due cognizance be taken of relativistic limitations on signal propagation. It is probable that this question will not be definitively resolved until efforts to incorporate general relativity into the consistent histories picture are brought to full fruition. However, sensitive observables may provide a concrete illustration of the fact that independent reality is destined to remain forever veiled.

As the author himself acknowledges, *Veiled Reality* is not a conventional textbook since, at least as far as philosophical considerations are concerned, it reflects the author's personal evaluation. However, that evaluation is buttressed by such a careful and erudite analysis that this work will provide a virtually indispensable supplement to courses on the foundations of quantum theory.

High Energy Astrophysics: Vol. 2

Malcolm S. Longair
Cambridge U.P., New York, 1994. 393 pp. $69.95 hc
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Contemporary astronomers study the universe using a wide variety of probes, measuring electromagnetic energy at wavelengths from radio waves to very-high-energy gamma rays, neutrinos from the Sun and stars, and high-energy cosmic rays. There are searches for the presence of ubiquitous dark matter and gravitational radiation. Vast amounts of data are steadily being collected with new ground- and space-based instruments and techniques. A textbook that can present all of this information in a coherent, comprehensive and readable manner as well as fit it into a theoretical framework is much needed.

Specialized texts exist on stellar structure, accretion phenomena, high-energy radiation processes, cosmic rays, cosmology and other topics, but no one brings the whole subject together with the brevity and clarity of a broad-band perspective. Malcolm Longair's *High Energy Astrophysics* texts are most welcome steps towards filling this void. Volume 1 was published in 1992; Volume 2 has now appeared and I understand that Volume 3 is on the way. Longair is a leading authority in astronomy and high energy astrophysics, and in *High Energy Astrophysics: Volume 2*, he provides an expert's view on this wide-ranging subject. The book will be welcomed by those of us who teach this subject to undergraduate seniors and first-year graduate students and by physicists who are interested in doing nonaccelerator astroparticle physics.

One of the main strengths of the presentations in Longair's second volume is strong emphasis on physical principles and the discussion of general results, rather than detailed discussion of particular models. The descriptive sections of the book are written in a clear and easily readable style. The majority of the quantitative derivations are described in sufficient detail (very little is left to: "it can be easily shown . . .", and the