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Book Review

Decoherence and Quantum Measurements. By Mikio Namiki, Saverio Pascazio, and Hiromichi Nakazato. World Scientific, Singapore, 1997, ix + 228 pp., $48.00 (hardcover).

Readers of this journal are surely aware of the tribulations of the quantum measurement theorist. Maybe it's Bohr's fault. He and his contemporaries put together so effective a set of rules that although many are unhappy with them, they give the answers. As a result, much of what was later written offered little more than intellectual satisfaction—a commodity of invariably controversial value. Quantum measurement theory has become a field in which many broadcast, few receive. In the last decades a new set of actors has appeared, quantum measurement *experimentalists*. Without minimizing the beauty and ingenuity of their work, 1 would say that they too are a disappointed lot: nowhere has any result contradicted or modified quantum mechanics.

At the theoretical level there have been exceptions to the broadcast/receive pattern. Notable among these is Wigner's 1963 article in *American Journal of Physics*, in which he mentions two problems in von Neumann's formalizing of Bohr's picture. One of them, a demonstration that Namiki, Pascazio, and Nakazato call a "no-go" theorem, shows that the postmeasurement state of a system cannot (if only quantum laws are used) be a mixed state if the initial state was not. (The other is the "WAY" theorem, the fact that no observable that does not commute with all additive conserved quantum numbers can be measured precisely.) Responding to this no-go theorem seems to have been the starting point for the "Many Hilbert Space Theory" of Machida and Namiki [*Prog. Theor. Phys.* **63**, 1457, 1833 (1980)]. The volume under review presents that theory and further developments based on it, much of this the joint work of the authors of the book.

Besides the work of Wigner, other results from the same general period include Bell's inequalities, which showed how to get the most

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mileage from the Einstein–Podolsky–Rosen critique. Some would date the modern era of quantum measurement studies to experiments aimed at checking this extreme prediction of quantum mechanics. But I would say that the most profound issues were those brought up by Wigner. It was his reasoning that forced us to push away from von Neumann's formalizing of Bohr's rules. The WAY theorem is (or should be) disturbing. But it is an instructive disturbance, in that the resolution of the problem forces on us the realization that apparatus is necessarily big. I refer to the work of Araki and Yanase ("AY" in WAY) in which they show that the likelihood of error (in measuring the noncommuting observable) is proportional to the ratio of the size of the microscopic system to that of the macroscopic measuring device. The no-go theorem is even more broadly relevant and even more insistent in demanding largeness and complexity in the apparatus. For example, the resolution of the problem to which I subscribed for many years is that which I learned in the fourth chapter of Gottfried's quantum mechanics textbook: although the density matrix has nonzero matrix elements between macroscopically different apparatus states, *for all practical purposes* these matrix elements are unobservable. The justification is the impossibility of constructing other devices that would connect these matrix elements. Now Gottfried's book dates to 1966. The next step *should* have been the realization that the way to put teeth into his assertions (quantitative teeth) would demand the tools of statistical mechanics, absolutely reasonable, given that the quantum measurement problem is also a problem of the interface between the macroscopic and microscopic worlds. But as far as I know, things didn't happen that way. What's amusing about this entire historical perspective is that a recent and relatively fashionable approach to quantum measurement theory, the decoherence approach, justifies its claims through calculations of the same sort that once were used for derivation of the master equation. The latter, generally studied in more prosaic disciplines such as chemistry, had all along been dealing with the issue of converting statements about amplitudes to statements about probabilities and, of course, using techniques common to statistical physics.

The 1980 response of Machida and Namiki to Wigner's no-go theorem was conceptually similar to that of Gottfried, but at the technical level rather different. Moreover, this difference was such as to allow them to make quantitative statements. Their Many Hilbert Space Theory incorporates the largeness and complexity of measurement apparatus in the following way. When an experiment is repeated many times, even with the same apparatus, each particle entering the apparatus sees a different environment, hence the Hilbert space for defining the apparatus (as in von Neumann's formulation) is different for each exemplar of the experiment.

When one looks at the sequence of experiments in this language, there *is* dephasing and one gets away from the no-go theorem. The success of the dephasing depends of course on the largeness of the apparatus. Largeness also enters when examining another assumption: the ability to isolate apparatus and system from the larger world. External interference, manifested in the macroscopic measurement apparatus as unavoidable fluctuations, is another justification for evasion of the no-go theorem. (The foregoing statements of the theory are those given in the book and represent a refinement of the original 1980 presentation.)

The desire to treat dephasing in a quantitative way leads the authors to a useful direction, the study of detailed models of apparatus, a context in which methods of statistical mechanics are natural. They subject a number of such models to scrutiny through their own Many Hilbert Space glass, from the rather artificial Coleman–Hepp model to more realistic ones, including some of their own devising (in particular, palatable extensions of Coleman–Hepp). What I especially like about such models is that anyone proposing a resolution of quantum measurement problems (or even defining what the problems are) had better be able to show how the resolution is implemented on any reasonable apparatus model. Actually, to return to my historical mode, I would even say that a more important advantage of a model is that it forces one to do normal theoretical physics, rather than unproductive philosophizing. [To my philosopher friends ... before condemning me for this nasty remark, please see my recent book where I philosophize(?) about the respective roles of philosophical and conventional scientific inquiry on quantum measurement problems.] In any case, Namiki & Co. were early leaders in the restoration of quantum measurement theory to its place in theoretical physics.

Another useful feature of the book is the analysis of particular experiments. Notable among these is the neutron diffraction work of Rauch and his collaborators. Now although I earlier characterized experimentalists as disappointed for failing to find that Nobel-qualifying disagreement with quantum theory, nevertheless I don't know any other way to proceed. In fact at a practical level (maybe) it was the ability to have ever better control of the environment—avoidance of dephasing, etc.—that has allowed one to even contemplate the degree of control necessary for quantum computation. As such, the discussion in this book of several experiments is useful to anyone wanting to do work that is *received* as well as broadcast. In fact, the book describes (implicitly) useful exchanges between the Japanese-Italian and the Viennese groups of the sort to which all we theorists should aspire.

A number of other topics of contemporary interest are discussed in the book, for example, the so-called quantum Zeno effect. Although the essential mathematical idea behind this effect was known to (and published by) von Neumann, it was only much later that it was posed as a challenge to quantum measurement theory ideas. There is some controversy as to whether recent experiments related to this effect are indeed observations of it in the full sense of the original formulation. There is no question, though, that the effect is a valid consequence of quantum mechanics, and recently there have been new applications of these ideas stemming from experiments that observed individual quantum jumps and the attempt to assign a time scale (different from lifetime) to the duration of the jump itself.

To some extent, this book is a broad review of the work of Namiki and his collaborators. Nevertheless, considerable background material is given, allowing the volume to serve general educational and reference purposes as well. I can recommend it to anyone wanting an orientation to quantum measurement theory and, in particular, wanting to focus on the Many Hilbert Space Theory.

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