LETTERS TO THE EDITOR

Comments Concerning "A New Look at the Quantum Mechanical Problem of Measurement"

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In a recent article Maxwell[1] urged reformulation of quantum mechanics so as to exclude the notion of measurement from the postulates of that theory. The need for such thoroughgoing revision is deftly argued in a philosophical vein; however, certain premises upon which the analysis is founded are without physical basis.

As is customary in discussions of the quantum theory of measurement, Maxwell contemplates the interaction of two ensembles, S and M, each initially characterized by a pure state (ψ_S and ψ_M). It is then claimed that (a) "if we designate the systems M as measuring instruments, quantum mechanics (QM) predicts that after each S interacts with each M, the measuring instruments have some definite state m_i," and that (b) "if... we regard the systems M as physical systems with associated state vectors, QM predicts that each M remains in a superposition of states m_i, unless further measurements are made on $S+M$." The seeming contradiction between (a) and (b) is the motivation for Maxwell's proposals.

Point (a), if we take it literally, embodies an unwarranted extrapolation of what QM actually predicts; point (b) is simply false.

(a) If we wish to make predictions concerning the results of measurements on systems in an ensemble S characterized by ψ_S, the quantal algorithm can only generate probability distributions for every observable; i.e., it can regularize the collective of meter readings in any M. This is an impressive capability but a modest one when compared to a capacity claimed by Maxwell for predicting the existence of definite postmeasurement *states* for each apparatus in M.

(b) Now, it is of course true that M, like all physical systems, can be discussed in terms of the state concept. Thus, in treating quantum theoretically the interaction between S and M, we may consider the dynamical evolution of the ensemble $S+M$ of composite systems, initially characterized by pure state $\psi_S \otimes \psi_M$. The state of M alone at any instant is determined by performing the partial trace operations called for by von Neumann's theory of composite systems. It is well known[2] that when S and M have interacted so as to produce correlations of the type which would justify calling the elements of M measuring instruments, then the state of the M ensemble alone is in fact a *mixture*, contrary to Maxwell's assertion (b). The *composite* $S+M$ will, to be sure, evolve from $\psi_S \otimes \psi_M$ only to future pure states; but quantum mechanics still assigns to M alone a mixture state. Indeed, quite apart from the problem of measurement, it is a mathematical truism that when two systems interact, their individual states are normally mixtures (though the systems may pass through pure states instantaneously as they evolve).

Finally, we should like to remark that investigations of the so-called problem of measurement are almost always rooted in some version of the celebrated metaphysical doctrine of state "reduction" or "projection." Maxwell's paper is no exception, for his assertion (a) attributes postmeasurement quantum *states* to *individual systems* (the measuring instruments). Although such attribution has become commonplace in the verbiage of physics and philosophy, it is quite irrational in a discipline so intrinsically statistical as quantum theory. Indeed, in the experimental practice of quantum physics, states are epistemically linked to experience only through the familiar frequency definition of probability. Hence, a quantum state actually refers to an *ensemble*, or to the preparation scheme which generated the ensemble, but never to a single element of an ensemble.[3] Accordingly, a quantum state cannot be determined by a single act of measurement but only after elaborate statistical analysis of data gathered from ensembles of measurements.[4]

Thus the resolution of Maxwell's measurement problem is simply to abolish from quantum mechanics all projection postulates—including Maxwell's version (a)—which attempt to formalize the measurement act by describing it in terms of untenable assignments of quantum states to individual systems. This suggestion to renounce the notion of state reduction, first made long ago by Margenau,[5] has the merit of conforming fully to the actual practice of quantum physics, wherein the projection postulate is seldom used and never required. Moreover, abandonment of the reduction idea for its inutility offers in addition the parsimonious bonus of invalidating much profuse philosophizing predicated upon imagined but nonexistent quantal inconsistencies.

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[1] N. Maxwell, Am. J. Phys. **40**, 1431 (1972).

[2] Discussions of this point appear in many places; the original analysis is probably that given by J. von Neumann in *Mathematische Grundlagen der Quantenmechanik* (Springer, Berlin, 1932), Eng. trans. by R. T. Beyer (Princeton U. P., Princeton, NJ, 1955), p. 437.

[3] J. Park, Am. J. Phys. **36**, 211 (1968).

[4] W. Band and J. Park, Found. Phys. **1**, 133 (1970).

[5] H. Margenau, Phys. Rev. **49**, 240 (1936); Phil. Sci. **4**, 352 (1937).

The Problem of Measurement—Real or Imaginary?

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As Band and Park correctly point out, the main thesis of my paper is that if the problem of measurement is to be resolved, a new, fully objective version of quantum mechanics (QM) needs to be developed which does not incorporate the notion of measurement in its basic postulates. Band and Park claim that my argument in support of this thesis is based on certain premises that "are without physical basis." I am, however, quite unable to accept their criticisms.

In the first place they argue that it is an "unwarranted extrapolation" to claim that "if we designate the systems M as measuring instruments, QM predicts that after each S interacts with each M, the measuring instruments have some definite state m_i." But this is simply the condition for the measuring instruments to measure the observable A. Only if each M ends up in one or other of n distinguishable physical states (e.g., a pointer in one of n possible positions) will the M's function as measuring instruments at all. Thus, the assumption that each M measures the observable A, together with QM, clearly does entitle us to conclude that each M ends up in one of n distinguishable physical states.

Secondly, Band and Park argue that after S and M have interacted, M is in a *mixture* and not, as I maintain, in a *pure state*. Now it is of course true that if we consider only measurements made on M, then M may be held to be in a mixture (and likewise for S). If, however, we consider measurements made on the joint systems $S+M$ (the case that I consider), then we cannot in general regard M and S as being in mixtures, for then we will not be able to predict correlations that exist between observables belonging to S and M. According to orthodox QM, if S and M are initially in pure states, then the joint system $S+M$ persists in a pure state, and S and M cannot, properly speaking, be said to have independent quantum states at all. D'Espagnat, who has discussed this kind of case, suggests that we should call the states of M and S after these systems have interacted *improper* mixtures, and carefully distinguish this from *proper* mixtures.[1]

None of this affects the *inconsistency* problem faced by orthodox QM in the slightest. This can be seen quite simply as follows. As we have already seen, the assumption that each M functions as a measuring instrument implies that after S and M have interacted each M is in one or other of n distinct physical states. But this conflicts with orthodox QM. A basic tenet of orthodox QM is that if an ensemble of systems is in a pure state,