Remarks on Measurements in Quantum Theory

Since the completion of my note[1] on a paper of Einstein, Podolsky and Rosen,[2] there have appeared two articles by Schrödinger[3] on the same subject. Mathematically the content of Schrödinger's papers and mine is essentially the same, although the emphasis is quite different. The interpretations given are exact opposites. I wish here to add a few words to the discussion.

Bohr[4] has emphasized that the essential difficulty with the argument of EPR lies in the assumption that whenever a system is not in mechanical interaction with other systems it may be regarded as having independently real properties. This assumption depends on the ascription of an undue significance to the fact that the systems are not connected in any way which finds a reflection in our description of the situation by means of a model. If it were tenable, it would provide an easy solution, quite acceptable to our habitual ways of thinking, of the problem of the relation of subject and object. In fact, however, the difficulties of this problem as they appear in quantum theory are not to be resolved by any such facile bit of analysis.

To make this assumption a definite basis for arguments, one must add some assertion as to the nature of the "real" properties of the "free," system. Being in agreement with Bohr's point of view, and wishing only to make clearer an interesting characteristic of quantum mechanics, I took as my additional assumption one which suggests itself from the content and manner of the usual discussions of the theory of measurement. My "Assumption A" is that a "free" system which was formerly coupled to an instrument is "really" in some one of a certain set of quantum-mechanical states, which are the eigenstates of the observable which the instrument is suited to measure. Assumption A has three important properties:

(1) The corresponding picture of the situation is in full accord with our habitual attitudes, and is the one we use in ordinary practice.

(2) The predictions derived from Assumption A for the sorts of cases which *actually occur* agree exactly with those of quantum mechanics.

(3) In more general cases, *realizable in principle* according to the postulates of the theory, there is flat contradiction between the formulas given by Assumption A and those of quantum mechanics. Therefore Assumption A is actually untrue.

The corresponding postulate chosen by Schrödinger is altogether different, on account of his different point of view. Since he agrees with the underlying assumption of EPR, he is careful to introduce no *a priori* "doubtful" element into his thesis. Thus he rejects (N, p. 827) Assumption A, and ends with taking as his criterion of "reality" just that of EPR: The "real" properties of the "free" system are the values of those observables whose values could be predicted "without in any way disturbing the system." On this basis one can give interesting considerations only about certain degenerate situations, such as that chosen as an example by EPR. Schrödinger accordingly devotes most of his mathematical discussion to a complete elaboration of this example. As was to be expected on general principles (F, footnote 11), the resulting picture of the situation is much more complicated than that originally drawn by EPR, and could scarcely be traced to so simple a source as an "incompleteness" of the theory; Schrödinger implies that it indicates some serious defect.

We may note two properties of this assumption:

(1′) It is, in the opinion of EPR and of Schrödinger, indisputably true *a priori.*

(2′) None of its assertions—it is innocent of actual predictions—ever comes into direct contradiction with the results of quantum mechanics; hence it cannot be either proved or disproved objectively.

According to the prevailing attitude in theoretical physics, (2′) is enough to consign all such assertions to the limbo of "meaningless statements."[5] Against this verdict (1′) is of no avail; for, as asserted already in the second paragraph of this letter, the assumption underlying such an opinion is definitely untenable: it is not correct to assume that the only physically significant relations are those which are directly obvious from a classical model. One striking experimental example is the collision of two similar particles. No matter how far apart the particles are when we try to collect one of them, the relative probabilities of finding it in different places are strongly affected by the "interference term" in the cross section; it is not really "free." (In this case, as in the one under consideration, there is of course nothing "magical" about the affair. The interference effect does not come in unless there has been an actual opportunity for the two particles to get interchanged,[6] just as in the case in hand there is never any relation between the systems without the existence of an actual dynamical interaction to start it.)

Thus there can be no doubt that quantum mechanics requires us to regard the realistic attitude as in principle inadequate. But it need not disturb at all our habit of taking such an attitude as a matter of practical convenience in the interpretation of experiments. In any measuring process actually used the "biorthogonal" expansion (F, Eq. (3)) is unique, and the experimenter concerns himself only with the observable and "pointer reading" which belong to this expansion. Thus Assumption A is a perfectly safe working hypothesis.

Schrödinger's misgivings (C, p. 555) about the fact that measurement involves actually a chain of object-instrument relations accordingly seem groundless. This question was discussed in full detail some years ago by Neumann,[7] and in my opinion his treatment is altogether adequate.

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[1] W. H. Furry, Phys. Rev. **49**, 393 (1936). Referred to as F.

[2] A. Einstein, B. Podolsky and N. Rosen, Phys. Rev. **47**, 777 (1935). Referred to as EPR.

[3] E. Schrödinger, Proc. Camb. Phil. Soc. **31**, 555 (1935) (referred to as C); and Naturwiss. **23**, 807–812, 823–828, 844–849 (1935) (referred to as N).

[4] N. Bohr, Phys. Rev. **48**, 696 (1935).

[5] Cf. W. Heisenberg, *The Physical Principles of the Quantum Theory*, p. 15, footnote.

[6] W. Pauli, *Handbuch der Physik* **24/1**, pp. 192–193.

[7] J. v. Neumann, *Mathematische Grundlagen der Quantenmechanik*, Chapter VI.