Space and Time in Mohrhoff's Interpretation of Quantum Mechanics

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A new interpretation of quantum mechanics has been developed in the past few years by Ulrich Mohrhoff.[1] Although it shares a number of features with the Copenhagen interpretation, it also differs from the latter in crucial respects, in particular in the way it views space and time.

In Mohrhoff's interpretation, the quantum wave function (or state vector, or density operator) obeys the Schrödinger equation exactly. The wave function, however, does not represent the evolving state of a system. It represents strictly a probability measure, providing either the subjective probability that the measurement of an observable actually carried out yields a given value, or the objective probability that the measurement, if it were (counterfactually) carried out, would yield a given value. More generally, Mohrhoff associates objective probabilities to counterfactual measurements on systems that are both preselected and postselected, in accordance with the rule of Aharonov, Bergmann and Lebowitz.

For Mohrhoff, an observable A associated with a quantum system has a value a if and only if a measurement (more generally, a fact) indicates that value. That is, the state vector of a system being $|a\rangle$ (an eigenvector of A with eigenvalue a) is not a sufficient condition for the value of A being equal to a. If the state vector $|\psi\rangle$ is not an eigenstate of A, so that more than one measurement result of A are associated with a nonvanishing probability,

[1] Mohrhoff's interpretation of quantum mechanics is presented in U. Mohrhoff, "What quantum mechanics is trying to tell us," *Am. J. Phys.* **68**, 728–745 (2000), as well as in a number of other published papers and preprints available in the quant-ph archives (`http://arxiv.org`). For an exchange on Mohrhoff's views see L. Marchildon, "Remarks on Mohrhoff's interpretation of quantum mechanics" (quant-ph/0303170, forthcoming in *Found. Phys.*) and U. Mohrhoff, "Do quantum states evolve? Apropos of Marchildon's remarks" (quant-ph/0307113, forthcoming in *Found. Phys.*).

then A is interpreted as being objectively indefinite or fuzzy.

These considerations apply in particular to the observable position. Space does not exist independently, but only associated with objects (e.g. particles) whose positions are effectively indicated. Since a measurement specifies a position in the reference frame of a given apparatus, only relative positions are defined, and only up to the accuracy with which they are determined. Hence physical space does not have the differentiation of a three-dimensional manifold. In the two-slit interference setup, for instance, space for the photon is up-slit down-slit differentiated only if the setup allows to determine which slit the photon goes through.

Although no Hermitian operator is associated with time in nonrelativistic quantum mechanics, the measurement of time necessarily involves position measurements (e.g. of a watch's needles). Time, therefore, like space, does not exist outside the context of measurements, and is not infinitely differentiated.

The views just outlined raise a number of questions which I intend to address.

- Spatial distinctions in a given region can be real for a particle and not real for another one. How is this to be understood?

- Since Mohrhoff assumes that quantum mechanics applies universally, the position of an apparatus is in general not sharp. Are there empirical consequences to the assertion that a particle's position is measured by means of an apparatus whose position is itself not sharp?

- Facts (in particular measurements) provide reality to space and time. To what extent do they lie within or without the framework of quantum mechanics?