Peer Review

Review of: "Fundamental Issues and Measurement Problem in Quantum Mechanics"

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I read this article with great interest. I think that the author correctly partitions the fundamental objects in the currently existing model for quantum mechanics into those

that carry definite meaning like the set of eigenvalues of an observable and those that carry meaning only after the measurement has been performed, like the wave function, state/density matrix, and probability distribution of an observable in a given state. However, these two apparently distinct types of quantities are very closely related. Indeed, an observable is modeled as a Hermitian matrix/operator in a Hilbert space, and its eigenfunctions/eigenvectors do carry definite meaning. An observable is not specified by just its set of eigenvalues; to specify it completely, one also requires the corresponding set of eigenvectors. Given a state/wave function, one can compute the probability distribution of the set of measurement outcomes on measuring an observable in this state completely in terms of the inner product between the given state/wave function and the set of eigenvectors of the observable. Moreover, two different observables may have the same set of eigenvalues but a different set of eigenvectors, which may force them even not to commute with each other. Thus, in this case, the two probability distributions of these two observables in a given state, although concentrated on the same set, will be distinct, and even worse, both of these two observables cannot be simultaneously measured. This is a form of the Heisenberg uncertainty principle. A mixed state is specified by two kinds of quantities: one, the set of eigenvalues of this mixed state density matrix, and two, the set of corresponding normalized eigenvectors. The former can be regarded as defining a classical probability distribution over the set of eigenvectors, and the eigenvectors define pure states, and one can compute the probability distribution of an observable in each of these pure states and then, by the law of total probabilities, one can compute the probability distribution of the observable in the mixed state. Thus, if we admit mixed states into the picture, then quantum mechanical probabilities are computed using a combination of classical probability distributions and quantum probabilities defined by pure states. One may be forced to accept that the classical probability distribution over the eigenvectors of the density matrix is not real; it exists only after a measurement, but the probability distribution corresponding to each pure state that appears as an eigenvector of the density matrix is real since it defines the "shape" of the density matrix. The author correctly suggests that the process of repeated measurement of an observable in a given state can be used to compute the probability distribution of the observable in this state using Von Mises' relative frequency interpretation, provided each measurement does not lead to the collapse of the state. Indeed, the state collapse postulate is one of the major hindrances in the current model of quantum mechanics. The author correctly suggests that a measurement apparatus should be regarded as partly classical and partly quantum mechanical. This view appears to be correct because the process of measurement involves a change in the state of the measuring apparatus, but this change in state is recorded by a conscious being, and hence it is only the conscious being who is capable of describing the change in state following measurement. However, the conscious being interprets the measurement result based on the change in the state of his/her brain, and in order to measure this change in his brain's state, another conscious being is required, and so on ad infinitum. This means that the process of measurement must be necessarily specified by an infinite sequence of conscious beings, each one existing outside the domain of the previous one. The infinite sequence of conscious beings will converge to a limiting conscious being who is capable of measuring the state of any system or conscious being within our universe. This limiting conscious being must therefore exist outside our universe, and we call such a being God.

As regards the author's analysis of relativistic quantum field theory and its relationship to non-relativistic first quantized quantum theory, I make the following observation: In relativistic quantum field theory such as QED, we have two kinds of field operators, one the Dirac wave operator field and two, the Maxwell vector potential field operator. The total second quantized Hamiltonian operator of this system is expressible as a quadratic form in these two wave field operators in the absence of interaction. In the presence of interactions between photons and electrons and positrons, we get a cubic term in the Hamiltonian that is quadratic in the Dirac wave operator field and linear in the Maxwell vector potential field. Thus, the total Hamiltonian operator of this interacting system can be expressed as quadratic plus cubic terms in the photon and electron-positron creation-annihilation operators, all in momentum space. Scattering probabilities between photon-electron-positron number states can then be calculated using

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the familiar rules of quantum mechanics based on perturbation theory. Equivalently, rather than working in Boson-Fermion number states, we can work in Boson-Fermion coherent states which are eigenfunctions of the positive frequency components of the electromagnetic field and of the Dirac wave field. In either case, we can compute the quantum average of the number density operator in position space for both photons and Fermions. This quantum average plays the role of the first quantized probability distribution of the positions of the electron-positron and photons in the given state. It should be noted that the number density operator of an electron in position space, for example, is psi(x)*psi(x) where psi(x) is the second quantized wave field operator of the Dirac field and likewise for the photon field with psi(x) replaced by the electric and magnetic field operator. Thus, using the momentum space representation of the wave fields in the form of creation and annihilation operators for photons and Fermions, it is possible to interpret the results of relativistic quantum field theory in the non-relativistic first quantized language of quantum mechanics.

I think that the paper is well written and provides a stimulus for further thought on the foundations of quantum measurement.

Declarations

Potential competing interests: No potential competing interests to declare.

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