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Comment on 'Protective Measurement and quantum Reality'

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Abstract

Protective measurements offer an intriguing method for measuring the wave function of a single quantum system. With contributions from leading physicists and philosophers of physics-----including two of the original discoverers of this important method------ 'Protective measurements and quantum reality' edited by Shan Gao explores the concept of protective measurement, investigating its broad applications and deep implications.

Keywords: protective measurement, quantum reality

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Quantum measurement is an important problem in quantum mechanics philosophy, it involves in various quantum mechanics interpretations. Notwithstanding more than 80 years' developments of quantum mechanics, it remains a hot topic of debate. Chinese physicist Shan-Gao edited 'Protective measurement and quantum reality' in 2013, and published it in Cambridge University Press in 2014, this is an interesting and excellent academic book. 19 famous physicists and philosophers of physics contribute 15 research papers on protective measurement in this book.

Protective measurements offer a new method for measuring the wave function of a single quantum system. For a common impulsive measurement, the state of the measured system is strongly entangled with the state of the measuring device during the measurement, and the measurement outcome is one of the eigenvalues of the measured observable. Aharonov, Albert and Vaidman introduced weak measurement during 1988-1990, a weak measurement is a standard measuring procedure with weakened coupling. Protective measurements are improved methods of weak measurements in the sense that they can measure the expectation values of observables on a single quantum system (Aharonov and Vaidman, 1993; Aharonov, Anandan and Vaidman,1993). A protective measurement differs from an impulsive measurement and a weak measurement in that the measured state is protected from being entangled and changed when the measurement happens.

Lev Vaidman points out that there are two methods for the protection of states: 'first, when it is a non-degenerate eigenstate of some Hamiltonian; second, based on the quantum Zeno effect,that frequent measurements of a variable for which the state is a non-degenerate eigenstate are performed.' [1,p19] Let us consider a Zeno-protection of the wave function on an ensemble, the statistical average gives the absolute value of the wave function in this measurement. To know the absolute value of the wave function in a particular point, we measure the projection on a small region of space around this point, and obtain one of the eigenvalues of the projection operator (0 or 1) on every measurement. He thought that there is no ontology beyond the wave function because of the failure of Bell inequalities, the PBR theorem and related results, even without protective measurements one can admit that a single quantum system's wave function is a sort of reality. Bell and his supporters failed to construct any local beables model, and the de Broglie-Bohm theory is a non-local beables theory. Removal of the wave collapse leads to the MWI. According to Everett's many worlds interpretation, everything is a wave, and the whole Universe is a highly entangled wave.

Unruh regarded protective measurement as a demonstration of the reality of certain operators and not of the wave function. Dickson considered protective measurement a a good reply for the realist against the empiricist. But Paraoanu thought that it is impossible to measure the wave function of a single quantum system due to the no-cloning theorem, Uffink also published his papers to challenge the possibility of protective measurements. Rovelli gave a comment of harsh criticism: "We argue that the experiment does not provide a way for measuring noncommuting observables without a collapse, does not bear on the issue of the 'reality of the wave function', and does not add any particular insight into our understanding (or non-understanding) of quantum mechanics." [2] So protective measurements can't give a decisive argument for the the wave function ontology, Dickson(1995) has convincingly argued that protective measurement can't decide between empiricism and realism about quantum mechanics, since protective measurement is entirely consistent with empiricism. In spite of this more subtle perspective and some critical studies of the technical and basic aspects of protective measurement, Gao has maintained the force of Aharonov and Vaidman's original argument: 'An immediate implication is that the result of a protective measurement, namely the expectation value of the measured system, as the system is not disturbed after this result has been obtained'.[1,p181]

Peter J.Lewis discussed protective measurement and various quantum mechanics interpretations in 'Measurement and metaphysics'. He thought that 'the ontological interpretation is that the wave function is a description of the properties of a single physical entity, whereas the epistemological interpretation is that the wave function is a description of the distribution of properties over an ensemble of similar physical systems' under all over scientific realism construal. [1,p94] In many-particles system, the motion of one particle depends on the location of all the other particles, no matter how distant. This makes it hard to combine Bohm's theory with special relativity, since special relativity can't define an action at a distance. This problem certainly arises in protective measurements, since they involve more than one particle. Peter.J.Lewis found that in GRW and Everett "particles" are only manifestations of the wave function, even in Bohm's theory, particle properties other than position are carried by the wave function, and protective measurements provide no new argument against ensemble interpretations. Peter Holland thought that the de Broglie-Bohm approach can provide a coherent account of measurement that dispenses with the problematic collapse hypothesis through the use of empty waves.[1,p148]

Aurelien Drezet pointed out that the work by Aharonov et al. on protective measurements confirms that pilot-wave theory is not classical, but it is the only known mathematical self-consistent and experimental conformable quantum ontology. [1,p177] According to Bell (1981), Everett's many worlds theory can be regarded as Borm's quantum potential theory without the continuous particle trajectories.[3]

Protective measurements play an important role in the discussion about the interpretation of quantum mechanics. Gao thought that protective measurements can give a new realism interpretation of wave function, this allows us to change the understanding of Born's probability rule, and Born's rule will have different meanings among various quantum mechanics interpretations. For example, the de Broglie-Bohm theory is strict determinism and it can't give objective randomness and Born's rule; Born's probability is subjective relative to observers in many worlds interpretation; The dynamic collapse theory can give an objective probability, but quantum randomness originates from classic noise fields outside of the wave function.[4]

Mauro Dorato and Federico Laudisa discussed various realism in 'Realism and instrumentalism about the wave function', including configuration-space realism, wave function-space realism, ψ-nomological realism. Contrary to instrumentalist regard the wave function as an only instrument to calculate probabilities by previous measurement outcomes, realist regard it as a new physical entity or a physical field of some sort. Albert regarded the wave function as a real physical field description in a fundamental high-dimensional space(Albert, 1996,2013,2015), this kind of wave function realism is also configuration-space realism.[1,122] North (2013) regarded wave-function realism as ontic structural realism. Goldstein and Zanghi(2013) defined the wave function as a nomic entity which guides the motion of particles. Once the controversy over the nature of the wave function is concerned, a new twist to the debate was provided by the so-called PBR theorem (Pusey, Barrett, and Rudolph, 2012). Assuming that quantum predictions are correct, the PBR theorem implies that a quantum state representing an individual system also represents a part or all of the physical reality of that system. In ‘Protective measurement and the PBR theorem’, Guy Hetzroni and Dabiel Rohrlich pointed out: ‘As for quantum theory itself, protective measurements demonstrate that a quantum state describes a single system, not only an ensemble of system, and reveal a rich ontology in the quantum state of a single system.’[1,p135] He concluded that protective measurements tells that if the two quantum states are the same, the systems have a lot in common, namely the expectation values of all operators measurable on the systems, and the PBR theorem tells us that if the two quantum states are different, the systems are in physically different states.

Maximilian Schlosshauer and Tangereen V.B.Claringbold examined the entanglement and state disturbance arising in a protective measurement and argued that these inescapable effects doom the claim that protective measurement establishes the reality of the wave function. They thought that quantum mechanics provides a formalism for relating and transforming probability assignments concerning outcomes of future measurements, and protective measurement is just an application, so it is not enough to solve the significant foundational and interpretive questions in quantum mechanics[1,p190]. Moreover,quantum information theory and decoherence theory are just like protective measurement, have not answered the difficult interpretive questions. P.J.Lewis(2004) noticed the differences in many body problem between classical mechanics and quantum mechanics: ‘In classical mechanics, the state of a system of N particles can be represented as a 3N-dimensional configuration space, and the configuration space representation is simply a convenient summary of the positions of all these particles. In quantum mechanics, however, the wave of an entangled N-body system, which is defined in a 3N-dimensinal space, cannot be broken down into individual three-dimensional wave functions of its subsystems.’[5,p42] So wave function realism seems to be an inescapable choice.

Vincent Lam thought that there are mainly three ways to understand the wave function as part of the ontology of QM. The first one is to consider the wave function as a physical object on its own like Bohmian mechanics. The second one suggested to consider the wave function as a law-like, nomological entity,physical entity in space and time. The third one is to interpret the wave function in term of the properties of ------the relations among------the local beables. Ontic structural realism regards the wave function as a physical structure, quantum non-locality is accounted for in terms of the quantum structure dynamics in this context, a clear interpretation of protective measurements is best understood as specific ways to probe the quantum structure represented by the relevant (effective,conditional) wave function, especially in Bohmian mechanics.

The physical meaning of the wave is an important interpretation problem of quantum mechanics. Several authors,including the discoverers of protective measurements, have given similar arguments supporting the implication of protective measurements for the ontological status of the wave function (Aharonov and Vaidman, 1993; Aharonov, Anandan and Vaidman,1993; Anandan,1993; Dickson, 1995; Gao, 2013a). If protective measurement had indeed established the reality of the wave function, then, without doubt, we would have happily concurred with Gao's assessment of protective measurement as a "paradigm shift in understanding quantum mechanics." [1,p192] Gao thought that there are two main problems in the conceptual foundations of quantum mechanics.The first one concerns the physical meaning of the wave function. The second one is the measurement problem. Gao proposed a new ontological interpretation of the wave function in terms of particle ontology. According to this interpretation, quantum mechanics is essentially a physical theory of the laws of random discontinuous motion of particles. Now Gao tries to argue that for an N-body quantum system, there are N subsystems or N physical entities with respective masses and charges in our three-dimensional space. According to this idea, Gao gives an intuitive expression of quantum entangled states.[5,p49-51] But Gao's viewpoint faces a further and harder question what the precise laws are, e.g whether the wave function undergoes a stochastic and non-linear collapse evolution. In addition, Gao finds that the spin of a free quantum is always definite along a certain direction, and it does not undergo random discontinuous motion. Because spin in quantum theory is a relativity effect, maybe Gao built his RDM model without regard to Einstein's relativity, as he declares: 'It is a further question whether the suggested particle ontology is complete in accounting for our definite experience and whether it needs to be revised in the relativistic domain.'[5,p67] Since Gao's RDM model accords with Epicurus's atomic swerve and Al-Nazzam's leap motion, we maybe find that a new relativistic RDM will realize Epicurus's nature philosophy dream completely in a near future: all particles' random motions are at the same speed, but not at different arbitrary speeds. Dirac's electron theory had found that electron's eigen speed is the speed of light in relativistic quantum mechanics.

This book is an anthology celebrating the 20th anniversary of the discovery of protective measurement.The topics include the fundamentals of protective measurement, its meaning and applications, and current views on the importance and implications of protective measurement. EPR, Bell inequality, quantum non-locality and quantum entanglement are very important problems in quantum mechanics interpretations, but this book doesn't discuss them deeply. Non-relativistic quantum mechanics is only a part of the whole quantum mechanics, this book hasn't discussed protective measurements in relativistic quantum mechanics and quantum field theory. In relativistic quantum mechanics and quantum field theory, the wave function takes the particle number representation and probability interpretation of the wave function loses its meaning .So we are difficult to define a single particle, maybe protective measurements lose their meaning or change their forms in the context of quantum field theory.

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