PROTECTIVE MEASUREMENT AND QUANTUM REALITY
SHAN GAO

Reviewed by Valia Allori

Protective Measurement and Quantum Reality: Toward a New Understanding of Quantum Mechanics
Shan Gao (*ed.*)
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This is an edited collection to celebrate the twentieth anniversary of the discovery of protective measurement by Aharonov, Vaidman, and Anandan ([1993]). The book explores the concept of protected measurement, investigating its broad application and its implications for the foundation of quantum mechanics.

The book begins with an introductory chapter in which Gao presents the standard formalism of quantum mechanics, according to which physical states are represented by the wave function and the physical properties are represented by the eigenvalues of appropriate operators (the eigenvalues–eigenstate link). The wave function evolves linearly except when a so-called von Neumann impulsive measurement is performed. This consists of a strong and short interaction, after which the state collapses into one of the eigenstates of the operator corresponding to the property being measured (the collapse rule). During such measurements, the system and the apparatus become entangled. In contrast, in protective measurements the state of the system is 'protected' from being too disturbed by the interaction.

In my understanding, protective measurements are similar to classical measurements. Consider a measurement of temperature using a thermometer: the device is specifically made not to perturb the state of the system so that the temperature reading is a reliable indicator of the temperature of the system before the measurement. The wave function can be reconstructed from the expectation values of observables, that is, with a series of protective measurements on identically prepared systems. Therefore, the wave function can be considered to be a property of the single system (as opposed to an ensemble of similar systems). As a consequence, it has been argued, the ensemble interpretation of the wave function is redundant. In fact, an ontic interpretation of the wave function, in which the wave function describes the property of a single system, is possible with protective measurements. This is argued in the second chapter by Lev Vaidman.

In the third chapter, Yakir Aharonov and Eliahu Cohen argue that the Heisenberg representation gives novel insight to the meaning of protective measurements. In contrast, Gennaro Auletta's is critical about them. He points out that that a measurement, in order to be such, has to do two things: (1) avoid the destruction of the state, and (2) extract information about the system. He then argues that protective measurements fail to be measurements, since they satisfy (1) but are unable to perform (2). Part I concludes with Lajos Diosi's contribution, in which he generalizes protective measurement for the joint measurement of several observables, and a chapter by Robert Flack and Basil Hiley, in which they describe a protective measurement of spin and its possible experimental realization.

Peter J. Lewis begins Part II with a critical evaluation of the philosophical significance of protective measurements. With his usual clear style, he argues that protective measurements provide a nice illustration of how 'quantum mechanics leads to a blurring of the distinction between the intrinsic properties of a system and the statistical properties of the ensemble of which it is a member' (p. 95). In Bohmian mechanics, as Lewis explains, it is better to think of contextual properties not as properties, otherwise they would be contextual. Nonetheless, Lewis writes, when such contextuality does not arise, it is natural to ascribe a family of properties to the wave function. Similarly, the property measured in a protective measurement is sometimes contextual. Thus according to Lewis, the wave intensity is best thought of as a family of related properties, rather than a single property of the system. If so, the agreement between the statistical properties of an ensemble of identical systems and the property of a single system is mysterious, and this is, according to Lewis, the main lesson of protective measurements.

In the eighth chapter, after providing us with a review of the various realist and anti-realist approaches to scientific theories, Michael Dickson argues against the philosophical significance of protective measurements. Mauro Dorato and Federico Laudisa, authors of the ninth chapter, discuss whether the Pusey, Barrett, and Rudolph (PBR) theorem (Pusey *et al.* [2012]) truly provides insight on the nature of the wave function. The PBR theorem is an argument for the reality of the wave function as an entity in itself, but Dorato and Laudisa instead deny that it succeeds; they argue that PBR is simply another no-go theorem and that it is hopelessly vague when specifying the significance of a system's having a 'real' physical state. In Chapter 10, Guy Hetzroni and Daniel Rohrlich compare and contrast the meanings of protective measurement and the PBR theorem. What do two quantum systems described by two quantum states have in common? If the states are the same, according to the protective measurements view, they have a lot in common (the expectation values of all the operators); while if the states are different, the PBR theorem says, they are in different physical states. In Chapter 11 Peter Holland discusses two objections to Bohm's theory based on protective measurements: the so-called 'surrealistic objection' (which amounts to the claim that Bohmian trajectories are not classical) and the problem of empty waves (which may be directly unobservable, but which can be given evidence of in terms of their interaction on other systems). In the twelfth chapter, Aurelien Drezet provides a nice historical overview of the birth and development of Bohm's theory. In particular, he shows how the surrealistic objection is as old as the theory itself, tying it to Einstein's objection to the theory. In their contribution, Maximilian Schlosshauer and Tangereen V. B. Claringbold criticize protective measurements, arguing that entanglement and state disturbance can never allow one to be sure a protective measurement has actually been performed. Chapter 14, by Vincent Lam, discusses the meaning and relevance of protective measurement in the primitive ontology framework, understood as a version of moderate structural realism. After presenting and defending his favourite approach against the alternatives, Lam argues that since the wave function is doesn't represent matter, at least on his approach, the surrealistic objection as well as the problem of unobservable empty waves never arise.

The final chapter of the book is also written by Gao. Having addressed some objections to protective measurements, he proposes 'a new ontological interpretation of the wave function in terms of particle ontology. According to this interpretation, quantum mechanics like Newtonian mechanics, also deals with the motion of particles in space and time. Microscopic particles such as electrons are still particles, but they move in a discontinuous and random way. The wave function describes the state of random discontinuous motion of particles, and at a deeper level, it represents the dispositional property of the particles that determines their random discontinuous motion' (pp. 227–8). This view is interesting but it closely resembles one of the variety of theories, called 'GRWp' in (Allori *et al*. [2014]), based on the notion of primitive ontology.

Be that as it may, the book constitutes an impressive collection, with valuable and interesting contributions from physicists as well as philosophers on a topic that is vastly under-investigated, especially within the philosophical community. I find this instructive: physicists, guided by the empiricist idea that something real should also be measurable, found protective measurements to be a game-changer in the realism-antirealism debate in the quantum domain, legitimizing the ontological view of the wave function. In contrast, as Lewis pointed out, the majority of the philosophical community was already convinced that the epistemic view was doomed and thus did not need protective measurements. *Protective Measurement and Quantum Reality* bridges this gap.

However, I think one prominent issue that ought to have been included has been overlooked. As we have seen, impulsive measurements destroy the state of the system through the collapse rule. This reminds me of someone trying to understand how the interior mechanism of a watch works by hitting it with a hammer. If this is correct, it seems incorrect to even call them 'measurements': they capture nothing of the system before the interaction. This is partly the reason why protective measurements were considered important. Nonetheless, consider the eigenstate–eigenvalue link, according to which properties are the eigenvalues of suitable operators representing the measured property. Why should we believe such a link captures a plausible way of thinking about properties? Think of mass or charge: these are usually considered properties of a system in the sense that they specifically characterize the system and thus are constant in time. The natural way to mathematically represent a property, therefore, seems to be with a number. Operators, instead, represent transformations: they receive an input and create an output. However, quantum mechanics, through the eigenstate–eigenvalue link, takes properties to be represented by operators. It is because of this assumption that many puzzling features of quantum mechanics arise, such as non-commuting properties, contextuality, and the like. In fact, the operator 'setting something on fire' and the operator 'putting water on it' do not commute, in the sense that their results depend on the order that they are applied. There is nothing puzzling about it if we think of operators as transformations. If, instead, we consider operators as properties, properties start behaving in funny ways. Nonetheless, instead of denying the assumption, as unreasonable as it is, people have traditionally preferred to think of quantum properties as highly non-classical (presumably for historical reasons impossible to capture here). The same is true in this volume: the assumption is taken for granted in each chapter, so a contribution that challenged it would have been valuable.

Let me close with a couple of minor stylistic observations. Conveniently, each chapter has its own bibliography listed at the end, so that one need not flip to the end of the book while reading. However, there is no consistency in citation styles throughout the volume: some use numbers, some names. Similarly, not all chapters have abstracts. The editor could have imposed a single system to provide more unity to the volume. Finally, an index for the volume would have been useful.

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