Preface to Volume 2, Issue 1 of Quantum Studies: Mathematics and Foundations

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We the editors of *Quantum Studies* would like to take this opportunity to thank everybody for the overwhelming response we have received to our request: “Think, reconsider, explore, create deep questions, use paradoxes as a tool for understanding, and finally: publish in this journal!”

This issue of *Quantum Studies* continues to deal with some of the most fundamental questions in quantum mechanics including nonlocality, collapse, uncertainty and determinism, together with more practical questions such as amplification and decoherence.

The first group of articles in this issue concerns the weak value. As is well known, since its introduction in 1988 by Aharonov et al. [1], the weak value has made a remarkable progression within the scientific world. After the initial experimental verification and acceptance as a physical phenomenon, it is now being used as a tool for both the further understanding of quantum puzzles and for precision measurements. *Quantum Studies* has previously published a number of articles concerning this issue [2–4].

The article by Jordan, Tollaksen, Troupe, Dressel and Aharonov “Heisenberg scaling with weak measurement: a quantum state discrimination point of view” looks at the question of precisely measuring a parameter via repeated interactions. In their case, the parameter is the interaction strength between a two-state system and a collection of photons. The authors demonstrate Heisenberg scaling on the precision of the parameter (that is the precision scales as the inverse number of photons, rather than the square root of the number of photons); however, the enhanced precision demands a measurement of the system state as characterized by the two-state vector following the interaction. One of the main points made by the authors is that the collection of photons coherently rotates the spin state to an orthogonal one, permitting the reliable determination of the unknown parameter.

In their article “A note on different definitions of momentum disturbance.” Rozema, Mahler, Hayat and Steinberg address a common misinterpretation of the uncertainty principle, namely, its use as a relationship between the precision of a measurement and the resulting disturbance caused to the post-measurement state. In 2003, Ozawa derived a relationship to properly describe this effect, and, in 2013, Busch et al. claimed that Ozawa’s work was

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misguided, deriving their own relationship. This article shows that both Ozawa and Busch's work are valid, but they describe different physics. Furthermore, this article demonstrates that Ozawa's work more closely represents the physics typically associated with a "measurement disturbance." In general, the detailed commentary about the physics described by Ozawa uncertainties is very useful to have especially since it comes from the very experimentalists who actually performed some of the measurements. The reader, thereby, gains many important additional insights that are all too often ignored in papers that focus more on the mathematical structure of the formalism.

In the article "Decoherence of weak values in a pure dephasing process," by Ban, the properties of weak values are explored in detail within an analytically solvable model of a single qubit coupled with a thermal bath of independent harmonic oscillators. In this well-motivated model, the author provides a clean numerical analysis and examples that convey intuition about the elaborate behavior and coherence of weak values in several distinct parameter regimes. In particular, the presence and robustness of anomalous weak values are examined in detail within this model.

Next, the article "On the Power of Weak Measurements in Separating Quantum States" by Tamir, Cohen and Priel, also addresses the problem of quantum state discrimination from a weak measurement perspective. Two different schemes are proposed through which the transition from weak to strong measurement is analyzed and the tradeoff between disturbance and accuracy is demonstrated. The later topic, strong measurement, is equivalent to a collapse, and furthers a theme often discussed in previous issues of *Quantum Studies* [5,6].

Another theme that we see addressed in the current issue concerns time symmetry. Historically, Aharonov et al. [7] suggested a two-vector time symmetric formulation of quantum mechanics. (And indeed the use of ABL in conjunction with weak intermediate measurements performed on pre and post selected ensembles led Aharonov et al to introduce the notion of the 'weak values'.)

In the article "Linear response theory for open quantum systems within the framework of the ABL formalism" by Ban, the theory of the linear response of a quantum system to external fields is developed for measurements ranging from typical strong (projective) measurements to weak measurements that cause minimal disturbance. The idea of a predictive response function dependent on the initial state is developed. When Ban subsequently subjects this post-selection, the theory is extended to a retrodictive response function dependent on the final state. This provides a time-symmetric description of linear response for a pre- and post-selected ensemble.

ABL and AAV also led directly to the quantum random walk [8] (QRW). Consider a classical random walk for which the coefficients for a step to the left or right are probabilities. N steps of step size 1 could generate an average displacement of $\sqrt{N}$, but never a distance larger than N . However when the steps are superposed with probability amplitudes, then the random walk can produce any displacement. This has proven to be a most useful tool in quantum information. For example, it was shown that implementation of the QRW would lead to a universal quantum computer as well as a quantum simulator (to study, e.g., phase transitions). Recent experimental realizations of QRW have been successful (trapped atom with optical lattice and ion trap; photons in linear optics).

The most recent proposal for a quantum algorithm which yields a speed-up for a quantum computer was based on QRW. Additionally, QRW offers one of the most successful connections with topological phases. This has already been implemented experimentally. QRW has thus resulted in the first demonstration of topological phases in 1D using linear optics.

In this issue of *Quantum Studies*, we have an article contributed by Konno called "Quaternionic quantum walks." In this article, the idea of a quantum random walk based on quaternion-valued unitary matrices is introduced and the preliminary features of this model are developed and compared with complex-valued and real-valued quantum walks. Stationary measures are developed to highlight the distinctions between these cases.

Next is an article by Revzen titled "Universal Maximally Entangled States Bases." Revzen introduces collective coordinates for maximally entangled states of two d -level systems in which several interesting structural features of these states are made more apparent. In particular, connections between these states and mutually unbiased bases are developed.

In an article titled "Toward a geometrical foundation for physics," Eitan proposes that quantum dynamics, and particularly QED, may emerge from a new geometric framework which he introduces, the core of which is the introduction of a new elementary mathematical object called an elementary metric oscillator (EMO) and an elaborate (not one-to-one) correspondence between the dynamics of EMOs and that of physical objects.

Finally, this issue continues [9] to host discussions concerning Bohm's approach to quantum mechanics as we have done in previous issues. In the article "Implications of a deeper level explanation of the deBroglie–Bohm version of quantum mechanics" by G. Grössing, S. Fussy, J. Mesa Pascasio, and H. Schwabl, the authors continued to further develop their efforts to build a model inspired by David Bohm's vision that Bohm's approach to quantum mechanics can lead to a new and different theory which would be even more precise than standard quantum theory. His hope was that the precision of his new theory would exceed the standard quantum theory in a way not unlike how the standard quantum theory is more precise than classical theory. Grössing et al.'s intuition comes from the analogy between the quantum wave-particle duality and bouncing droplets in an oscillating medium. Although their theory is still not complete, their interesting analysis of possible types of nonlocality which such a theory might exhibit is important for all attempts to explain why it is that the world that we experience has three dimensions.

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