Preface: Quantum Theory: Reconsideration of Foundations 6

This volume presents the proceedings of the International Conference Quantum Theory: Reconsideration of Foundations-6 (QTRF6) held in Växjö, Sweden, 11-14 June 2012. The organizing committee of the Conference included: H. Atmanspacher (IGPP, Freiburg, Germany/ ETH Zurich, Switzerland), I. Bengtsson (Stockholm University, Sweden), A. Brandenburger (New York University Stern School, USA), C. Fuchs (Perimeter Institute for Theor. Physics, Canada), E. Haven (University of Leicester, UK), A. Hosoya (Tokyo Institute of Technology, Japan), A. Khrennikov (Linnaeus University, Växjö, Sweden), M. Ozawa (Nagoya University, Japan), S. Stenholm (Stockholm University, Sweden), J. Tollaksen (Chapman University, USA).

The conference was supported by the Rector's Strategic Fund and the International Collaboration Fund of the Chair of Mathematics, Linnaeus University. The conference is part of the series of Växjö conferences on foundations of quantum mechanics (Bohmian Mechanics-2000, Foundations of Probability and Physics-2000, 02, 04, 06, 08,11, Quantum Theory Reconsideration of Foundations-2001, 03, 05, 07, 09, 12), Advances in Quantum Theory 2010. The conference was primarily based on five special sessions:

General Questions of Quantum Foundations, A. Khrennikov and S. Stenholm, organizers; *Weak Measurements*, A. Hosoya, M. Ozawa, J. Tollaksen, organizers; *Wolfgang Pauli's Notion of Quantum Mechanical Incompleteness*, H. Atmanspacher and C. Fuchs, organizers; *Quantum Foundations and Experiment*, A. Migdall and S. Polyakov, organizers; *Quantum-like decision making: from biology to behavioral economics*, A. Brandenburger, A. Khrennikov and E. Haven, organizers.

A wide spectrum of topics was presented in talks at this conference: quantum foundations (especially, Heisenberg's uncertainty relation and its generalizations) and information, mathematical formalism of quantum theory, philosophy, methodology of measurements and results of new exciting experiments on testing foundations of quantum mechanics and quantum field theory. A number of talks on applications of the mathematical formalism of quantum mechanics to cognitive science, psychology (nonclassical decision making) and finances were given in the special session Quantum-like decision making: from biology to behavioral economics.

Talks on foundations of quantum mechanics and related papers in philosophy represented a large spectrum of interpretations: from the orthodox Copenhagen interpretation to the Växjö interpretation. A majority of talks were devoted to new achievements in conventional quantum theory. However, attempts to go beyond this theory were also well represented; a possibility of experimental violation of the basic probabilistic laws of quantum mechanics (including Born's rule) were discussed (G. Weihs, W. Hofer, G. Groessing, A. Khrennikov,

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H. De Raedt, M. Kupczynski). Thus quantum theory was enlighten from all possible angles: from a complete theory which is developed through new applications, especially to quantum information, to ``quantum mechanics as emergent phenomenon''.

As was remarked, the very basic issue of quantum foundations, Heisenberg's uncertainty relation and its generalization due to M. Ozawa, was in very center of conference debates. Yu. Hasegawa presented the talk devoted to theoretical foundations of Ozawa's generalization of Heisenberg's uncertainty relation. He correctly pointed out that the original Heisenberg's uncertainty relation is purely statistical in origin and it has nothing to do with the real precision of individual measurement (of e.g. position or momentum). (This viewpoint on the Heisenberg's uncertainty relation was also presented many years ago by L. Ballentine.) M. Ozawa proposed (also many years ago) to complete the original Heisenberg's uncertainty relation by additional terms related to the precision of measurement beyond the standard deviations involved in relations proposed by W. Heisenberg. M. Ozawa also predicted that the original Heisenberg's uncertainty relation could be violated in some experiments, while his version of the uncertainty relation holds true. Yu. Hasegawa presented results of an experiment in neutron interferometry supporting claims of M. Ozawa. A. Steineberg presented results of another experiment supporting Ozawa's theory. This topic, both theory and experiment, attracted a lot of interest of conference participants.

Asides from the general excitement (experimental evidence of violation of Heisenberg's uncertainty relation), some participants of the conference, in particular, A. Khrennikov and P. Lahti expressed doubts that Ozawa's theoretical model of precision in individual measurement matches the real experimental situation. A controversial talk was presented by W. Hofer, who claimed that the uncertainty relation of Heisenberg is violated by experimental data from surface physics. This claim was the subject of much debate at the conference.

The role of experimental technicalities to match subquantum models with experimental statistical data was emphasized in the talks of A. Khrennikov, who presented a wave resolution of the wave-particle duality and H. De Raedt, who presented a corpuscular resolution of the wave-particle duality. Thus, as at the previous conferences, the ``beyond quantum approach'' was characterized by diversity of positions and models.

This year, a tradition of presenting novel experimental work from the world's leading experimental groups was continued with the experimental talks organized as a special session. The interest here is threefold. First, direct tests aimed at quantum mechanics and subquantum models are certainly interesting to the community. S. Clark (from C. Monroe group in Maryland, USA) covered a unique Bell test experiment, in which a detection loophole was closed for the first time. A. Migdall presented preliminary data obtained in collaboration with M. Genovese's group in Italy aimed at testing the validity of the De Raedt

theory. The common theme behind theoretical and experimental efforts was not a coincidence: it stems from a format of the forum in Växjö, and highlights the importance of bringing experimentalists and theorists together to exchange ideas and results. Second, an equally important topic covers experiments whose outcomes predicted by quantum optics differ from those of classical theory. This not only illustrates the outstanding predictive potential of traditional quantum mechanics, but also opens new avenues of verification of quantum theory, beyond Bell tests. A report by A. Migdall on a demonstration of a receiver with error probabilities below the standard quantum limit is one example of research relevant to this. While it has been understood for a long time that quantum mechanics allows for receivers that are better than what is classically possible, it is only now that a quantum receiver taking practical advantage of this idea has been experimentally realized. T. Graham (from P. Kwiat's group in Illinois, USA) discussed experimental progress with non-classical states of light generated in a parametric down-conversion process - these types of sources as pioneered by Kwiat's group has become a de-facto standard in quantum optics, owing to high purity of non-classical states that this process offers. Lastly, a third type of experiment critically studies real-world constraints on quantum resources relative to what has been proposed for ideal resources that only exist in a theorist's mind. Along these lines, S. Polyakov, in collaboration with the group of G. Solomon presented a recent characterization of single-photon states from pulsed sources and showed that the standard metric used to describe purity of single-photon states does not work well for sources in pulsed mode. They demonstrated a new method of measurement that helps overcome this issue. Based on the positive impact of the experimental special section on a foundational conference aimed primarily at theorists, we hope that this tradition will continue.

H. Atmanspacher and C. Fuchs organized a special session on "Wolfgang Pauli's Notion of Quantum Mechanical Incompleteness". At various places in his unpublished manuscripts and in his correspondence with M. Fierz and C. G. Jung, Pauli expressed his uneasiness with a worldview treating matter in a way "totally neglecting the inner state of the observer". At the same time, he made it very clear that he was not thinking about "an incompleteness of quantum theory within physics, but rather an incompleteness of physics within the totality of life". The article by H. C. von Baeyer gives a historical account of Pauli's friend and colleague M. Fierz, whose deep and broad insights in many avenues of knowledge often served as a guiding light for Pauli's thoughts in physics and psychology. The relation of the physical and the mental, as both Pauli and Fierz conceived it, is a relation of complementarity. A. Plotnitsky addresses how Pauli took up this notion from Bohr, who was familiar with it from W. James' ``Principles of Psychology" and imported it into physics. Plotnitsky analyzes Pauli's arguments with Bohr on the difference between the concepts of detached and participatory observers, and he underlines their fundamental disagreement as far as Pauli's dissatisfaction with the completeness of physics is concerned.

The idea of a participatory observer a la Pauli (and also J. Wheeler) is a key to C. Fuchs' approach to understanding measurement in quantum theory. His basic program is to try and interpret quantum measurement as epistemically as possible (as a theory of knowledge, as it were), which even leads to a view of Born's rule in terms of "subjective" probabilities. With this program, he hopes to find out whether a purely epistemic account of quantum theory leaves us with a residuum that must be considered ontic. Methodologically, this is an example of what philosophers call a "via negativa" approach.

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