Preface of the Special Issue Probing the Limits of Quantum Mechanics: Theory and Experiment, Volume 1

Andrei Khrennikov, Hans de Raedt, Arkady Plotnitsky & Sergey Polyakov

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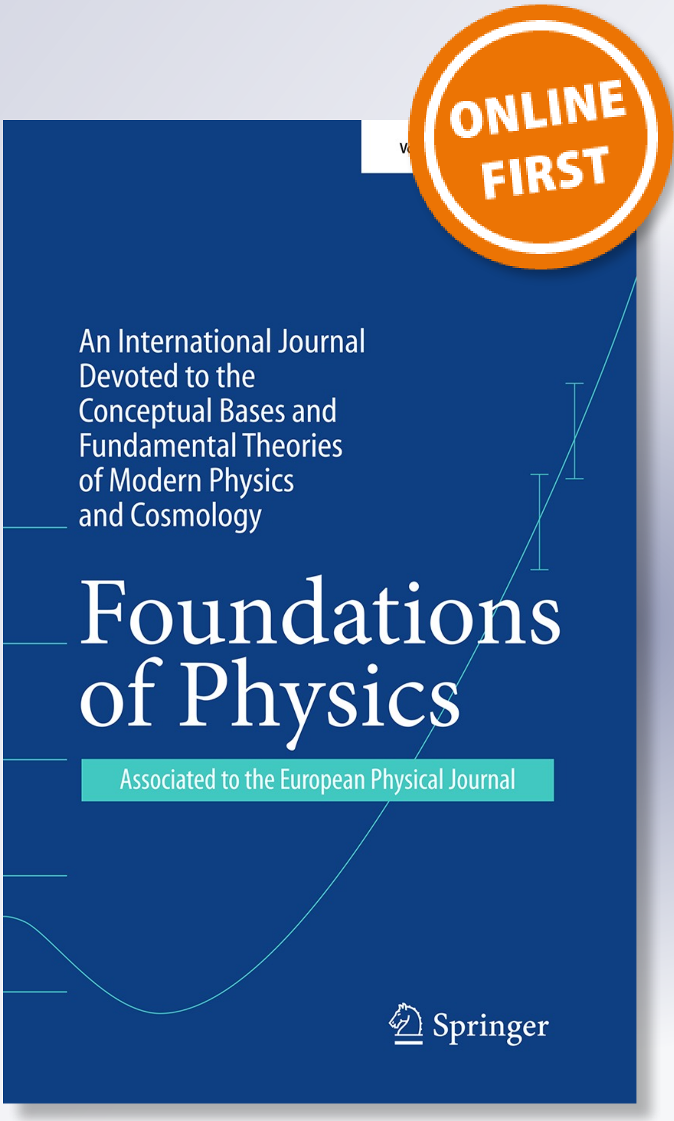

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EDITORIAL

Preface of the Special Issue Probing the Limits of Quantum Mechanics: Theory and Experiment, Volume 1

Andrei Khrennikov[1] · Hans de Raedt[2] · Arkady Plotnitsky[3] · Sergey Polyakov[4]

The quantum information revolution significantly increased the interest in the foundations of quantum mechanics. Nowadays this topic is no longer only a business of philosophers and historians of science, but also of practicing physicists and of physical practice, theoretical and even experimental. While complemented by the more traditional philosophical analysis, foundational studies are now based much more firmly on complex theoretical models, advanced mathematics and numerical simulations, very closely related to experiments. The intensive development of quantum information and quantum technologies continuously generates novel foundational problems. One such topic is foundational justification of the project on quantum random generators. Foundationally, this project is based on von Neumann's claim concerning the irreducibility of quantum randomness, conceived in an unconditional opposition to classical randomness. However, some among recent developments of quantum information theory brings new dimensions to this question, specifically in relation to the problem of violation of Bell type inequalities. In general the field of quantum information is a great playground for testing various interpretations of quantum mechanics—especially of the information nature, such as operational approaches to quantum theory or, more recently QBism (Quantum Bayesianism) based on the subjective interpretation of probability.

✉ Andrei Khrennikov
andrei.khrennikov@lnu.se

1 International Center for Mathematical Modeling in Physics, Engineering, Economics, and Cognitive Science, Linnaeus University, Växjö, Sweden

2 Zernike Institute for Advanced Materials, University of Groningen, Groningen, The Netherlands

3 Theory and Cultural Studies Program, Purdue University, West Lafayette, IN, USA

4 National Institute of Standards and Technology, Gaithersburg, MD, USA

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If Feynman is correct by saying that "nobody understands quantum mechanics", one must seriously investigate how this lack of understanding affects the application of quantum theory to nanoscale phenomena and the efforts to integrate nanoscale components into a functional system. It is commonly assumed that these applications do not significantly or even meaningfully depend on foundational questions, and that the general framework of quantum mechanics and its specific findings are sufficient for describing new forms of nanostructures from their basic physics to their device function. But is there a need to understand the science of what we are dealing with, or should we just "shut up and calculate", as we are still often advised to do?

This volume in the first of two volumes presenting theoretical and experimental viewpoints on several foundational problems that have a direct relation to quantum information and technology. A variety of other foundational problems of quantum physics as well as the philosophical contributions will be presented in volume 2.

1 Contextuality

A new approach to contextuality proposed by Dzhafarov, Kujala, and Larsson is based on the idea that contextuality is measured by the highest correlation one can achieve between random variables measuring one and the same property in different contexts as one imposes various joint distributions on all random variables in the system. In their paper, "Contextuality in Three Types of Quantum-Mechanical Systems", they derive necessary and sufficient conditions for contextuality in a broad class of quantum systems. This class includes, as special cases, Klyachko-Can-Binicioglu-Shumovsky-type, Einstein-Podolsky-Rosen-Bell-type, and Suppes-Zanotti-Leggett-Garg-type systems.

2 QBism

In the article "Why I am not a QBist", L. Marchildon examines Quantum Bayesianism, a recent prominent and controversial development of the epistemic view of quantum states, in other words, a view that consider quantum states as interments, moreover, subjective interments of knowledge, rather than (ontologically) describing the behavior of quantum system themselves. Drawing analogies with other instrumentalist views of theories, Marchildon argues that QBism, although logically consistent, fails to provide a satisfactory solution to the conceptual problems of quantum mechanics.

3 Bell's Inequality

At present, the interpretation(s) of the violation of Bell type inequalities is one the most exciting quantum foundational problems. This is a problem of huge complexity. Here quantum foundations meet foundations of probability and statistics, and this meeting is not peaceful at all. As a result, the process of clarification of interrelation between classical and quantum probability and of the role of such issues as (non)locality, (un)realism is often chaotic, with cyclic argumentation for and against. However, recent years witnessed a fresh line of theoretical research, namely, deeper statistical analysis of the corresponding data.

Such statistical analysis is impossible and even meaningless without taking into account all sources of randomness involved in Bell's type experiments. One of such sources, namely, randomness of selection of orientations of polarization beam splitters, is widely discussed in literature, including it relation to the role of free will and super-determinism. At the same time this randomness is not present in correlations which are calculated for the fixed pairs of settings. A detailed analysis of this sort of randomness and its contribution to (non)violation of Bell's type inequalities is presented in the paper of A. Khrennikov "CHSH inequality: Quantum probabilities as classical conditional probabilities". Here quantum correlations are interpreted as classical conditional correlations. The crucial point is that conditional (classical) correlations can easily violate the CHSH-inequality.

The paper of M. Kupczynski "Bell Inequalities, Experimental Protocols and Contextuality" also contributes to this topic; it makes a strong case against quantum nonlocality, counter-factual definiteness, and the irreducible randomness of quantum measurements. The author argues that his detailed analysis of probabilistic and non probabilistic models used to prove Bell, CHSH and CH inequalities shows that these models are inconsistent with experimental protocols and with the contextuality of quantum theory.

4 Measurement Theory

A new type of mathematical model "the context-invariant quasi hidden variable model" was introduced in the article by E. Loubenets "Context-invariant and local quasi hidden variable (qHV) modelling versus contextual and nonlocal HV modeling." The model reproduces the Hilbert space description of all the joint von Neumann measurements for each Hilbert space. In particular, it yields new bounds on the maximal violation by a multipartite quantum state of Bell inequalities.

G. Jaeger's article, "Measurement and Fundamental Processes in Quantum Mechanics," offers a new perspective on an important component of the current debate concerning quantum foundations, J. S. Bell's criticism of measurement, by offering and analysis of J. Schwinger's theory of quantum measurement (rarely addressed in literature on the subject). This analysis is developed in part by contrasting Schwingers theory with other approaches to understanding quantum measurements, most especially those of N. Bohr and J. von Neumann. The article explores several key physical and philosophical implications of Schwingers theory, in particular in view of the role of quantum-field-theoretical considerations argued by Schwinger to be necessary for properly understanding quantum-mechanical measurement, rather than measurement procedures used in quantum-field-theoretical regimes. Ultimately, the article argues that Schwinger's theory may provide a more adequate response to Bell's criticism than those of Bohr, von Neumann, and several other currently available approaches to measurement in quantum mechanics.

5 Beyond Quantum

As was already pointed out, Einstein's dream for completing the quantum theory to have the causal description for individual events still inspires physicists to create new models for apparently nonclassical processes matching with the probabilistic predictions of quantum mechanics. Those theories that can be directly falsified by experiment are especially interesting here. For example, prequantum random field theory, recently developed by A. Khrennikov makes predictions concerning a dependence of a second order correlation function on an intensity of the nonclassical light. Inspired by the lively discussions in Växjö during last years on the fundamental origin of photons, the Gaithersburg group of NIST designed and conducted an experiment aimed at searching for the dependence of a second order correlation function on an intensity of the nonclassical light, the results of this experiment and their analysis are presented in the paper of J. K. Peters et al. "Experimental Bounds on Classical Random Field Theories." They have found no such dependence, and shown that quantum theory adequately describes their experiment. However, their work does not directly falsify the prequantum random field theory, and thus leaves the question unresolved, raising the stakes in search for the ultimate answers to "the quantum riddle", as Einstein once called it.

We hope that this issue will be useful for experts working in all domains of quantum physics and quantum information theory: theoreticians, experimenters, mathematical physicists.