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Editorial: Uncertainty relations and their applications

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Editorial on the Research Topic
Uncertainty relations and their applications

Quantum mechanics is regarded as a significant achievement in our exploration of the microscopic world. It helps us understand the initial seeds of the whole Universe, explore the formation of the matter world with elementary particles, and manipulate the quantum materials composed of a huge number of atoms. Quantum mechanics plays a vital role in revealing the intrinsic nature laws and forms the basis of modern science and technology. Therefore, increasing focus on quantum physics is of great significance to any possible breakthrough in quantum engineering and technology. As one of the most fundamental and vital concepts of quantum theory, the uncertainty relation is at the heart of quantum physics, yielding various versatile applications. In this regard, we organized the Research Topic "*uncertainty relations and their applications*" in Frontiers in Physics. Currently, nine contributed articles have been collected on this topic. The first part of contributions has been made on the theoretical exploration on the various form of quantum uncertainty relations. By introducing the uncertainty interval, a concept derived by combining lower and upper bounds together, Xiao et al. use the entropic uncertainty relations to formulate lower bounds of variance-based uncertainty relations, which successfully establishes the connections between different forms of uncertainty relations. Concerning the Heisenberg uncertainty, Fan et al. raise an interesting question: what will happen if the mean values are replaced by weak values in the Heisenberg uncertainty relation? To answer this question, they delve into the case of position and momentum measurements in a simple harmonic oscillator, with pre-selected states as eigenstates and the post-selections as the superposition states. Their results show that the original Heisenberg limit can be improved in this case, replaced by a weak value canonical uncertainty relation holding for simple harmonic oscillators in coherent states. Thus, the work of Fan et al. provides an important supplement to the field of uncertainty relations with weak measurement and go beyond the standard Heisenberg limit.

Second part of contributions focus on the applications of the uncertainty relations for the manipulatable quantum systems in lab. In particular, Fang et al. investigate both linear-entropy-based uncertainty relation and quantum entanglement in a two-dimensional (2D) Ising model. By the derived effective Hamiltonian and quantum renormalization group (QRG) equations of the model, they have found by numerical analysis that both the uncertainty relation and the quantum entanglement can be used to detect quantum phase transition (QPT), while the linear-entropy-based uncertainty relation can be a more powerful indicator for the detection of the QPT. This result may pave a promising pathway to observe QPTs of the solid-state system by means of the uncertainty relation. Additionally, for a finite size system, it would be difficult to find critical points and critical exponents through the standard Finite-Size Scaling (FSS) approach, Khalid et al. propose an alternative FSS method in which the truncation of the system is made in the Hilbert space instead of the physical space and apply this approach to calculate the critical point for the QPT of Quantum Rabi Model. They also provide a protocol for the implementation of this method on a digital quantum simulator using the Quantum Restricted Boltzmann Machine algorithm. On the experimental side, based on their generalized unitary uncertainty relation theory and proposed uncertainty relations of non-Hermitian operators, Zhao and Zhang design an experimental implementation which can test the uncertainty relation for two non-Hermitian operators through the Mach-Zehnder interferometer. Also, Liu et al. report an experimental test on the coherence uncertainty relations based on the classical shadow algorithm. They examine the tightness of various lower bounds and draw a novel conclusion that tightness of quantum coherence lower bounds depends on the reference bases and the purity of the quantum state. This may deeply reveal the relationship between uncertainty relation and characteristics of quantum system.

Associated with uncertainty relations, quantum resources are also of great significance in quantum engineering and technology. The third part of contributions concerns on the various quantum resources related to uncertainty relations. Amongst these, nonclassicality is one of the valuable quantum resources related to the quantum aspect of photons. Fu et al. argue that the requirement for nonclassicality measurement in the sense of Glauber-Sudarshan is convex. Based on the non-convexity of nonclassicality measure in Ref. [1], they find that this measure is intrinsically connected with the Wigner-Yanase skew information, a measure of quantum uncertainties. Inspired by this, Fu et al. propose a faithful measure of nonclassicality, which is convex. Entanglement is another essential resource of quantum information processing. In order to characterize quantum entanglement, the analysis of various bases in the state space is in demand. Tao et al. systematically investigate the constructions of unextendible entangled bases with a fixed Schmidt number k (UEB*k*) in a bipartite system by using generalized weighing matrices and propose three ways to construct different members of UEB*k*s.

In conclusion, this editorial is created to present the latest progress of the Research Topic: *Uncertainty relations and their applications*. Our special thanks to all authors of the articles published on this Research Topic for their valuable contributions and the Frontiers in Physics team for the technical assistance with publishing.

Author contributions

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