Discovery of uncertainty relations beyond the Heisenberg

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In the quantum world, the famous Heisenberg uncertainty principle bounds the product of the variances of two incompatible observables such as the position and the momentum of a particle by the Planck constant. Heisenberg, one of the founders of quantum mechanics, gave only an intuitive formulation of this principle, using thought experiments. Later, the uncertainty relation was generalized by Robertson for general observables and it was proved that the product of the variances of two incompatible observables is bounded by their commutator (a quantity that gives the difference between two physical observables when multiplied in succession).

However, the flaw of the Heisenberg relation lies in the fact that due to its product structure, it cannot fully capture the concept of incompatible observables. The lower bound for the product of variances can be zero even for noncommuting observables, making the relation trivial. In the past, there have been other formulations of uncertainty relations in terms of bounds on the sum of information-theoretic quantities that measure the uncertainty of measurement outcomes for two incompatible observables.

However, in the laboratory, the experimentally measured error bars are directly connected to the variance and not to information-theoretic quantities such as the Shannon entropy.

In the present *Physical Review Letters* paper [L. Maccone and A. K. Pati, *Phys. Rev. Lett.* (2014)], these authors have proved two new uncertainty relations that bound the sum of variances of two incompatible observables. In contrast to the well-known Heisenberg-Robertson relation, which bounds the product of variances, these new relations always give non-trivial bounds for all incompatible observables.

For example, the new relation tells us that the sum of the variances of the position and the momentum of a quantum particle (such as a single photon or a single electron) is bounded by the Planck constant plus an additional positive term, thus making the uncertainty relation much stronger than before. In contrast, the usual Heisenberg uncertainty relation implies that the sum of the variances of the position and the momentum for any particle is always bounded by the Planck constant.

Therefore, the new relations derived in this paper can have fundamental implications, as they not only capture the incompatibility of observables; they also do it in terms of quantities that are physically measurable. Since the uncertainty relations have fundamental significance in quantum physics, quantum information, and quantum entanglement, it is believed that the present results will have deep impact on quantum physics, quantum information and general physics as well.

More information: The paper is available online: journals.aps.org/prl/abstract/ … ysRevLett.113.260401

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