Macroscopic state-independent quantum contextuality

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(Contributed oral, session B)

By “quantum contextuality” we mean the impossibility of reproducing quantum mechanics by models in which the outcomes of measurements on individual systems have predefined values which are independent of which other compatible measurements are jointly performed on the same individual system. Analogously, “quantum nonlocality” is the impossibility of reproducing quantum mechanics by models in which the outcomes of measurements on parts of composite systems have predefined values which are independent of which other measurements are performed on distant parts of the same individual system. A fundamental difference between quantum contextuality and quantum nonlocality is that while, in order to experimentally observe quantum nonlocality, the system must be prepared in some specific quantum states, to observe quantum contextuality, the system can be in any quantum state.

Recently, we have shown that a state-independent experimental proof of quantum contextuality is possible [1]. Specifically, we have shown that any two-qubit quantum state violates by the same amount the following inequality valid for any non-contextual model,

$$\langle ABC \rangle + \langle abc \rangle + \langle a\beta\gamma \rangle + \langle Aa\alpha \rangle + \langle Bb\beta \rangle - \langle Cc\gamma \rangle \leq 4,$$

(1)

where $A, B, \ldots, \gamma$ are some specific observables with possible outcomes $-1$ and $+1$, and $\langle ABC \rangle$ is the average of the products of the outcomes of the measurements on the same system of three compatible observables $A, B,$ and $C$. This state-independent quantum contextuality test has been recently performed with ions [2] and photons [3].

On the other hand, the state-independent quantum contextuality is universal in the sense that, for any quantum system in which nontrivial contextual models can be defined, there are inequalities valid for any noncontextual model, which are violated by the same amount for any quantum state [4].

So far, for all known “noncontextuality inequalities”, the state-independent violation decreases as the complexity of the quantum system (i.e., the number of degrees of freedom) increases. This suggests that state-independent quantum contextuality is unobservable for “macroscopic” systems. Here we prove that the amount of violation can increases exponentially with the number of qubits of the system. This suggests that state-independent quantum contextuality would be observable in systems with many degrees of freedom, since the exponential violation predicted by quantum mechanics would compensate the expected low visibilities of the experiments.

References