Quasiprobability and quantum paradoxes in electronic counting statistics

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The impossibility of measuring non-commuting quantum mechanical observables is one of the most fascinating consequences of the quantum mechanical postulates. Hence, to date the investigation of quantum measurement and projection is a fundamentally interesting topic. We propose to test the concept of weak measurement of non-commuting observables in mesoscopic transport experiments, using a quasiprobabilistic description. We derive an inequality for current correlators, which is satisfied by every classical probability but violated by high-frequency fourth-order cumulants in the quantum regime for experimentally feasible parameters. We further address the creation and detection of entanglement in solid-state electronics, which is of fundamental importance for quantum information processing. We propose a general test of entanglement based on the violation of a classically satisfied inequality for continuous variables by 4th or higher order quantum correlation functions.

To this end, we propose a derivation of the time-resolved full counting statistics of electronic current based on a positive-operator-valued measure [1]. Our approach justifies the Levitov-Lesovik formula in the long-time limit, but can be generalized to the detection of finite-frequency noise correlations. Since current operators at different times do not commute, the high-frequency correlation functions of the current are realization of this fundamental quantum question [2]. We formulate this problem in the context of measurements of finite-frequency current cumulants in a general quantum point contact, which are the subject to ongoing experimental effort. We then show that the unusual properties of weak measurements can be interpreted in terms of a real quasi- probability, which can take negative values [3]. Our interpretation agrees well with predictions and measurements of the current fluctuations in mesoscopic junctions. Finally, we propose a cumulant-based Bell test for mesoscopic junctions without the charge quantization assumption [4]. Therefore, we have constructed a classical inequality for non-local correlation measurements involving up to 4th order correlations. A spin-resolved quantum measurement on tunnel junctions violates this inequality in an experimentally accessible range of temperatures, voltages and time/frequency resolution.

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