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Quantum measurements of work fluctuations

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Work is one of the central notions in (statistical) mechanics and thermodynamics. In fact, it is *the* quantity that connects thermodynamics and mechanics. Unlike in the macroscopic regime, at the microscale, fluctuations of work become relevant and sometimes even dominant, which makes their characterization a question of fundamental importance. In classical mechanics, the solution is straightforward: to each phase-space trajectory, one assigns the value of the work performed along it. In the quantum regime, however, there is no notion of trajectory, and defining fluctuations of work becomes problematic, especially for coherent processes. In this work, we approach the problem in the most general form, and, therefore, consider closed systems and ask whether there exists at all a definition satisfying two minimal conditions: (1) Average work should be given by the difference of initial and final average energies of the system and (2) the classical limit should be respected. Among many possible ways to define the classical limit, we choose arguably the weakest one – the Jarzynski equality must hold for all thermal initial states. First, we prove that the only work measurement scheme satisfying (2) is the widely-used two-projective-energy-measurements (TPEM) scheme, where the energy is measured both at the beginning and at the end of the process. Second, we show that there exists no state-independent measurement protocol that can simultaneously satisfy (1) for all states and coincide with the TPEM scheme for energy-diagonal initial states. Having thus ruled out the possibility of existence of universal, state-independent generalized quantum measurements for work estimation, we go on asking whether there exist state-dependent schemes capable of satisfying both (1) and (2). It turns out that such measurements do exist, and we describe a simple and intuitive scheme based on the notion of *ergotropy* and its fluctuations as given by a time-reversed TPEM scheme.

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