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Dephasing and Dissipation in Qubit Thermodynamics

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Abstract:

The Jarzynski identity, $\left\langle e^{-\beta W}\right\rangle = e^{-\beta \Delta F}$, is perhaps the most recently discovered simple general formula in elementary statistical mechanics. Here it is assumed that both the initial and final states of the system are equilibrium ones at the same temperature, β^{-1}; the difference between free energies of these states being ΔF. Work W done on a system by a source splits into the "useful" work, which is the change U in the internal energy of the system itself, and into heat dissipated into the environment, Q, such that $W = U + Q$.

To relate such a process to the thermodynamic fluctuation relations, the full work, W, needs generally to be considered. There are various ways to measure work-related quantities in a quantum setup. The original proposal put forward as the so-called two-measurement protocol (TMP), where the state of the system is measured first before the work is applied, and second after the application of this work. This yields naturally

the difference in the internal energy, $U \equiv E_f - E_i$, where E_i, E_f refer to the energies of the states of the system observed in the initial and final measurements, respectively. For a closed system, not interacting with the environment during the driving period, $Q = 0$, this yields then the whole work. The true interesting case is, however, that where the system is open ($Q \neq 0$), which cannot be captured by the simple TMP. Because TMP has nevertheless become a common measure of work in actual experiments on quantum systems, it is interesting to see quantitatively how good or bad an estimate it yields for the full work in realistic open setups.

In this work [1] we present results on fluctuation relations on U for a generic two-level system with definite environmental relaxation/excitation rates and dephasing at finite temperatures. As a solvable example, we study a qubit in the weak dissipation limit (where one can employ the so-called quantum jumps method [2]), and demonstrate (both analytically and numerically) that dephasing and relaxation render the Jarzynski and Crooks fluctuation relations (FRs) of non-equilibrium thermodynamics intact. On the contrary, the standard two-measurement protocol, taking into account only the fluctuations of the internal energy, U, leads to deviations in FRs under the same conditions. We relate the average $\langle e^{-\beta U} \rangle$ with the qubit's relaxation and dephasing rates, and discuss this relationship for different mechanisms of decoherence.

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[2] J. Dalibard, Y. Castin, and K. Mølmer, Phys. Rev. Lett. **68**, 580 (1992).