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Analytic theory of system-bath correlations in nonequilibrium fermionic impurities

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Coupling of the system to its environment inevitably leads to the generation of system-bath correlations. Such correlations are often thought to be negligible in the weak-coupling Markovian regime. This is because the Markovian master equations are commonly derived using Born approximation that assumes factorization of the system-bath state. However, recent numerical studies have demonstrated that information-theoretic measures of system-bath correlations can take non-negligible values also in the Markovian regime. In particular, the system-bath mutual information can approach the Araki-Lieb bound on its maximum value.

Here we present an analytic theory quantitatively describing the system-bath correlation measures, such as mutual information or entanglement negativity, in single fermionic levels coupled to a fermionic bath in the weak-coupling Markovian regime [1]. In this regime, correlations are shown to depend only on the reduced state of the system and intensive thermodynamic parameters of the bath (temperature and chemical potential). For a situation when the impurity is initialized in an out-of-equilibrium state and then relaxes to equilibrium, the theory shows the generation of transient system-bath correlations, which are maximized at the relaxation half-time and vanish in the long-time limit. In the case when impurity is driven to a nonequilibrium steady state by the applied voltage (i.e., the difference of chemical potentials of two baths), the theory demonstrates the presence of a steady-state system-bath entanglement above a certain threshold voltage, which depends only on the temperature and asymmetry of coupling strengths to the baths. The validity of this theory and its range of applicability are established by numerical simulations.

[1] K. Ptaszyński, M. Esposito, arXiv:2306.09680 (accepted in Phys. Rev. B).

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