A statistical approach for the many-body density of states of spinless fermions

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The description of out-of-equilibrium many-body systems requires going beyond the low-energy physics and local densities of states. Many-body localization, presence or lack of thermalization and quantum chaos are examples of phenomena in which states at different energy scales, including the highly excited ones, contribute to the dynamics and therefore affect the system's properties. To quantify these contributions, one has to obtain the many-body density of states (MBDoS), a function whose calculation becomes challenging even for quantum non-interacting identical particles due to the difficulty in enumerating states to account for the exchange symmetry. In the present work, we introduce a statistical approach to evaluate the MBDoS in the case of systems that can be mapped into free fermions. The starting point of our method is the principal component analysis of the filling matrix F describing how M electrons can be configured into K single-particle energy levels. We show that the two principal components of F and corresponding eigenvectors can be analytically calculated and one can treat them statistically to recover the many-body spectrum and the MBDoS. We illustrate our method in two classes of problems that are mapped into spinless fermions: (i) non-interacting electrons in a homogeneous tight-binding model in 1D and 2D, and (ii) interacting spins in a chain under a transverse field.