Signatures of Quantum Chaos and fermionization in the incoherent transport of bosonic carriers in the Bose-Hubbard chain

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Introduction

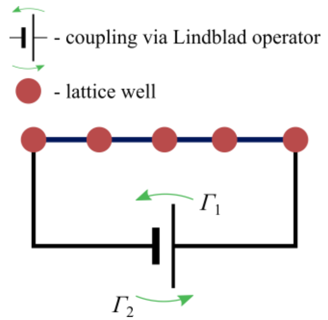
One of the central questions to be addressed with the open BH chain, both theoretically and experimentally, is the stationary current of Bose particles across the chain and its dependence on the strength of interparticle interactions. To approach the outlined problem, we introduce a specific boundary driven BH model which conserves the number of particles in the system. Although the introduced model cannot be directly related to ongoing laboratory experiments, it admits a comparative theoretical analysis with the closed BH system.

The Model

We consider the BH chain of the length L with incoherent coupling between the first and the Lth sites. The coupling is described by the following Lindblad operators

$$\hat{\mathcal{L}}_1(\hat{\mathcal{R}}) = \hat{V}^\dagger\hat{V}\hat{\mathcal{R}} - 2\hat{V}\hat{\mathcal{R}}\hat{V}^\dagger + \hat{\mathcal{R}}\hat{V}^\dagger\hat{V},$$

$$\hat{\mathcal{L}}_2(\hat{\mathcal{R}}) = \hat{V}\hat{V}^\dagger\hat{\mathcal{R}} - 2\hat{V}^\dagger\hat{\mathcal{R}}\hat{V} + \hat{\mathcal{R}}\hat{V}\hat{V}^\dagger,$$



where $\hat{V} = \hat{a}_1^\dagger\hat{a}_L$. Thus, the master equation for the carrier density matrix $\hat{\mathcal{R}}$ reads

$$\frac{d\hat{\mathcal{R}}}{dt} = -i[\hat{\mathcal{H}},\hat{\mathcal{R}}] - \Gamma_1\hat{\mathcal{L}}_1 - \Gamma_2\hat{\mathcal{L}}_2,$$

where

$$\hat{\mathcal{H}} = -\frac{J}{2}\sum_{l=1}^{L-1}(\hat{a}_{l+1}^\dagger\hat{a}_l + \mathrm{H.c.}) + \frac{U}{2}\sum_{l=1}^{L}\hat{n}_l\,(\hat{n}_l - 1)$$

is the Bose-Hubbard Hamiltonian.

Results

We demonstrate that the system described above exhibits different transport regimes. These regimes are determined by the ratio between the tunneling and interaction constants in the Bose-Hubbard Hamiltonian. Additionally, we will show that the nonequilibrium many-body density matrix of the bosonic carriers in the chain exhibits a transition from a regular spectrum to an irregular one.