Localized-Interaction-Induced Quantum Reflection and Filtering of Bosonic Matter in a One-Dimensional Lattice Guide

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1D Bose-Hubbard Hamiltonian

Atomic bosons in a quasi-1D optical lattice are very well described by the 1D Bose-Hubbard Hamiltonian

$$H = -J \sum_{i=1}^{L} (b_i^\dagger b_{i+1} + b_{i+1}^\dagger b_i) + \sum_{i=1}^{L} V_i \, n_i + \frac{1}{2} \sum_{i=1}^{L} U_i n_i (n_i - 1) \, , \qquad (1)$$

where b_i is the bosonic annihilation operator for an atom at the i-th site in the lattice of total length L, and n_i is the atomic population at the site.

Here J is the tunneling (hopping) energy, V_i is an additional external axial potential, and U_i is the on-site inter-atomic interaction strength.

These parameters J, V_i, U_i can be controlled during experiments with a high level of accuracy and flexibility.

Tilted optical lattice and nonlinear barrier

In our paper we investigate the dynamics of a initially localized cloud of bosonic atoms with a tilded optical lattice, obtained with the additional axial potential

$$V_i = -E\, i \tag{2}$$

where E is the tilt. Moreover, we consider a nonlinear barrier, induced by a site-dependent interaction strength

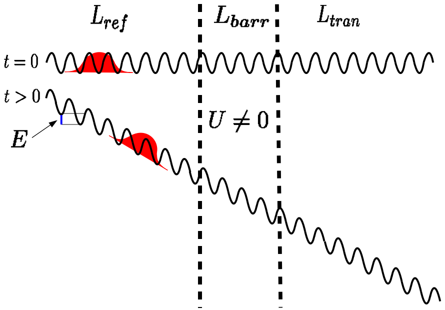
$$U_i = \begin{cases} U & \text{if } L_{\rm ref} \leq i \leq L_{\rm ref} + L_{\rm barr} \\ 0 & \text{elsewhere} \end{cases} \tag{3}$$

at the center of the lattice.

By using the **time-dependent density-matrix-renormalization-group** (t-DMRG) method we study numerically the time evolution of the bosonic cloud in the optical lattice.

Quantum dynamics: tunneling through a nonlinear barrier

Initially the bosonic cloud of atoms is placed at the edge of the left part of the lattice of size $L_{\rm ref}$. The tilt E drives the particles towards the central interaction zone (nonlinear barrier) of size $L_{\rm barr}$.



Some atoms are reflected after the collision with the nonlinear barrier ($U \neq 0$) while other atoms are transmitted into the right-hand side, composed of $L_{\rm tran}$ sites.

Main results

We find that the nonlinear barrier induces an anomalous quantum reflection and transmission of incident wave packets.

In particular, a sufficiently strong nonlinear barrier reflects only bosonic components with multiple onsite occupancies, while single-occupancy components are transmitted. In other words, for a large $|U|$ the transmitted wave packet has no more than one particle per site.

This property resembles the scattering of classical waves on a nonlinear potential barrier: weak incident waves pass it, while large-amplitude ones bounce back.

Please, read the paper

– The paper reports detailed numerical results for different values of the physical parameters.

– In the paper one also finds an extended discussion of the adopted 1D Bose-Hubbard Hamiltonian and numerical procedure.