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Quantum chaos with atoms in a laser field

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Single cold atoms in an optical lattice, formed by counter propagating laser waves, are ideal objects for testing some foundation principles of quantum physics and quantum chaos. We review theory and experiments on quantum chaos with atoms in optical lattices.
We find in numerical experiments a manifestation of Hamiltonian chaos of the fundamental atom-light interaction in the diffusive-like center-of-mass motion spontaneously emitting atoms which can be observed in real experiments.
Key Words: cold atoms, optical lattices, quantum chaos

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Quantum chaos with atoms in a laser field

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The mechanical action of light upon neutral atoms is at the heart of laser cooling, trapping and Bose-Einstein condensation. Atoms in an optical lattice, formed by a laser standing wave, is an ideal system for studying quantum nonlinear dynamics. Operating at low temperatures and controlling the lattice parameters, experimentalists now are able to tailor optical potentials and manipulate with internal and external degrees of freedom of atoms. Experimental study of quantum chaos has been carried out with ultracold atoms interacting with a periodically modulated optical lattice. To suppress spontaneous emission and provide a coherent quantum dynamics, atoms in those experiments were detuned far from the optical resonance. We review recent experiments on quantum dynamical effects with cold atoms in a laser standing-wave field: dynamical localization and its suppression, chaos assisted tunneling, Levy flights and others.

A new arena of quantum nonlinear dynamics with atoms in optical lattices is opened if we work near the optical resonance and take the internal dynamics into account. In the Hamiltonian approximation, when one neglects spontaneous emission, the coupling of internal and external atomic degrees of freedom has been shown to produce a number of nonlinear effects in rigid (i.e. without any modulation) optical lattices: chaotic Rabi oscillations, chaotic atomic transport, dynamical fractals and Levy flights [1]. In reality the dynamics of atoms in near-resonant laser fields is not deterministic and continuous because of spontaneous emission, a kind of a shot noise which is not small. We simulate atomic ballistic transport in a standing-wave laser field in the framework of a Monte Carlo stochastic wavefunction approach in which the coherent Hamiltonian evolution is interrupted at random times by spontaneous emission events. It is shown in numerical experiments and confirmed analytically that the character of spatial and momentum diffusion of spontaneously emitting atoms changes abruptly in the atom-laser detuning regime where the deterministic Hamiltonian dynamics has been shown to be chaotic. Thus, we find a manifestation of underlying Hamiltonian chaos in the diffusive-like center-of-mass motion which can be observed in real experiments [2].

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