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How to probe the microscopic onset of irreversibility with ultracold atoms

R. Bürkle, A. Vardi, D. Cohen, and J.R. Anglin

arXiv: 1903.04834 (2019)

While the laws of quantum mechanics are reversible, a coupling to an environment makes the dynamics of a system usually irreversible. Bürkle et al. propose an experiment with atoms in a double-well potential to test the microscopic origin of irreversibility in a relativity small physical system. They consider a double-well system, which each of the sites having a single bound state that can be populated by bosonic atoms subject to interactions. The experiment starts with a large energy difference of the two double well eigenstates, and at this time for state preparation atoms also are coupled to a reservoir, so that they thermalize to settle in site #1. The detuning subsequently is reduced, so that atoms can tunnel to site #2 and in the following then increased back to its initial value, such that for a reversible evolution all atoms would return to site #1. Burke et al. however find a parameter range where not all atoms tunnel back to site #1, i.e. the dynamics is not fully reversible (Fig. 1).

To understand the background of this numerically confirmed effect, it is helpful to map the system onto a classical one-particle phase space problem with the canonical variables q and p. The mapping is possible given that the large number of particles of the original problem results in many degrees of freedom. The treatment shows that the irreversibility is here not due to chaos, which would be the usual assumption, but rather only to a separatrix, which separates regions in phase space with different long-term behavior. The two-state system, despite interatomic interactions, still is simple enough that no dynamical chaos occurs. In general, under a slowly changing Hamiltonian, a dynamical separatrix can grow or shrink. An ensemble that is initially inside a shrinking separatrix can thus be squeezed out of it, spilling into a larger phase space volume. Even without chaos or noise, the ensemble then swirls through this larger volume finely, effectively filling it in a coarse-grained sense. If the change in the Hamiltonian is slowly reversed, the larger volume does not all fit back into the initial region—and so not all of the ensemble can find its way back to the initial state. The result is probabilistic irreversibility even in an isolated system without chaos.

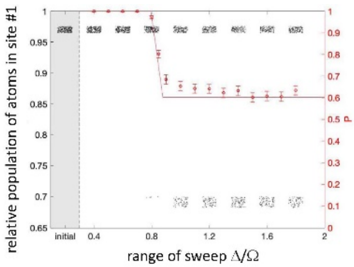

Fig. 1: Predicted normalized number of particles returned to site #1 after the sweep versus the sweep range in units of the tunnel coupling between sites.

Coherent perfect absorption of nonlinear matter waves

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When coupling light into a lossy optical cavity for a certain input coupling (i.e. transmission of the incoupling mirror), one can fully suppress the back reflection of light. This is achieved when the reflection of the incoming laser beam from the incoupling mirror (perfectly) destructively interferes with the backwards directed cavity outcoupling. A few years ago, another optics experiment generalized this to a setting with two beams coupling light into the two opposite sides of an optical cavity with partially transmissive mirrors, for which a perfect incoupling into the lossy cavity requires to besides the incoupling amplitudes also to match correctly the relative phase of the beams. The resulting suppression of output from the two ports was named coherent perfect absorption.

Müllers and colleagues have demonstrated the phenomenon of coherent perfect absorption for nonlinear matter waves. The experiment uses a Bose-Einstein condensate of rubidium atoms in a one-dimensional optical lattice. With a focused electron beam, atoms in a single lattice site are removed. A schematic of the experimental situation is shown in Fig. 1. The loss is counteracted by tunneling of atoms from both sides into this lattice site, and when neglecting interactions between atoms the precise analog of the above described optics experiment can be realized. Other than photons atoms however do have an interaction from interatomic collisions, which gives rise to a nonlinear term in the equation of motion. Müllers and colleagues experimentally find that the phenomenon of coherent perfect absorption here does exist despite the nonlinearity (Fig. 2). Even more, due to the interactions the phenomenon can be observed easier than in the linear case, because the nonlinearity provides an attractor dynamics towards the coherently absorbing state.

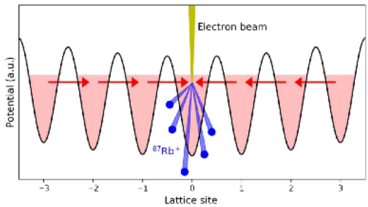

Fig. 1: Principle of experiment.

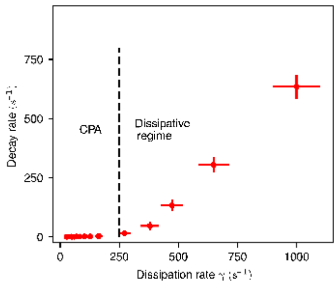

Fig. 2: Observed condensate decay rate versus the induced dissipation. Coherent perfect absorption (CPA) operates up to a certain dissipation, while for larger dissipation rapid decay is observed.

Non-adiabatic storage of short light pulses in an atom-cavity system

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arXiv: 10903.10922

Light pulses can be stored in atomic systems and retrieved at a later point in time. This is of interest e.g. in memories for quantum network applications, but on a more general level also for demonstrating control of quantum systems. In previous work, for such light storage experiments adiabatic transfer techniques have been used, with the most simple configuration being a three-level system with two stable ground states and one spontaneously decaying excited state. Adiabatic transfer with the so-called STIRAP scheme over a dark superposition of the two ground states, with the composition of the dark state varying in time as controlled by a "control" laser pulse, allows for a reversible mapping of a second "signal" beam laser pulse into an atomic coherence and back on demand when again activating the "control" beam laser pulse.

Macha and colleagues demonstrate light storage and retrieval in an atomic coherence with a non-adiabatic technique. This allows for a faster operation than the adiabatic limit. In their experiment, a 5 ns long pulse was stored and released (Fig. 1), the corresponding time being shorter than the upper electronic state natural decay time. During the pulse sequence, the electronically excited state is also populated - an issue which would not be possible without significant losses when operating with sequences of duration longer (or comparable) to the upper state natural lifetime. This shows that the operational principle is different than the STIRAP method, for which (assuming an idealized situation) no population of the excited state occurs. The experimental realization by Macha et al uses single rubidium atoms within in a fiber-based Fabry-Perot resonator.

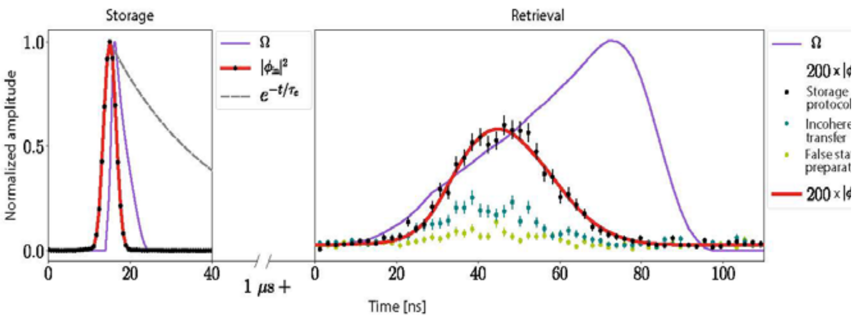

Fig. 1: Temporal variation of signal (black dots) and control field (violet line) during storage and retrieval.