Coherent Quantum Tunneling and Macroscopic Superposition States in Optical Lattices

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The AC-Stark shift of a set of interfering laser beams together with the Zeeman interaction with external magnetic fields provide flexible mechanisms for coherently controlling atomic wave packets. When detuned far from atomic resonance these optical lattices can trap cold atoms with minimal dissipation, and thus provide an ideal environment for observing quantum coherent phenomena. We consider a one dimensional lattice of double wells produced by counterpropagating linearly polarized laser beams, and a static magnetic field transverse to the laser wave vectors. The distance between the wells is determined by the angle between the beam polarizations, and is on the order of the optical wavelength, which is macroscopic when compared to the atomic dimension. As such, an atom that is coherently distributed on both sides of the double wells may be considered to be a "Schrödinger cat". From an experimental perspective the double well potential has a built-in polarization gradient, so that tunneling is accompanied by a precession of the atom's angular momentum. This provides a label for left/right positions in the double well, and allows real-time observation of coherent tunneling as an oscillation in the magnetization - something that is typically not possible in a condensed matter system.

Localized states in the left or right wells, in addition to symmetric/antisymmetric Schrödinger cat states, can be prepared through adiabatic changes in the potential, produced by an additional longitudinal magnetic field. This allows for the study of the coherent inhibition of tunneling when a harmonic driving field is applied. Furthermore, one can overcome inhomogeneous broadening of the tunneling frequency, which occurs due to variations in the laser intensity across the lattice, by using a generalization of the spin echo technique . The optical lattice thus offers a flexible environment for quantum state control and measurement. In addition, once the intrinsic incoherent processes have been suppressed, dissipation may be re-engineering into the system in the form of well characterized fluctuations in the lattice parameters, allowing for a detailed study of the decoherence process.