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Engineering matter-wave tunneling in optical lattices

Over the last two decades, there has been considerable theoretical interest in the coherent control of tunneling in strongly driven potential wells. Depending on the experimental parameters, the effect of the strong driving is to suppress or restore tunnelling.
We have measured the dynamical suppression of tunnelling predicted in refs. [1,2] using Bose-Einstein condensates in strongly driven periodic optical potentials. Tunneling between the sites of a periodic array is inhibited by applying a periodically varying potential, e.g. by shaking the array back and forth, and as a consequence the tunneling parameter J representing the gain in kinetic energy in a tunneling event is replaced by $|J_{eff}| < |J|$. Moreover, our results [3] show that the tunneling suppression occurs in a phase-coherent way in spite of the strong shaking. This might ultimately lead to the possibility of controlling quantum phase transitions by strong driving of the lattice.
When the ground states of adjacent potential wells of a periodic potential are tuned out of resonance by a static potential the resonant tunneling between the ground states is suppressed. We have measured this tunnelling suppression and the related Wannier-Stark localization of the wavefunction [4] by observing the spatial tunnelling of the condensate atoms. When photons of an appropriate frequency are present whose energy bridges the gap created by the static potential, tunneling is partly restored (photon-assisted tunnelling). The role of the photons is played by a periodic shaking of the lattice at frequency that leads to the creation of sidebands around the carrier frequency of the laser beam. Our results agree well with theoretical predictions [5] and demonstrate the usefulness of optical lattices for studying solid-state phenomena.

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