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Prospects for strong localization of matter waves by scattering from atoms in a lattice

YVAN CASTIN, Laboratoire Kastler Brossel, Ecole normale supérieure (Paris)

Non-interacting matter waves in a disordered potential may exhibit localized states, that is eigenstates with an energy above the potential and with a square integrable wave-function. This intriguing quantum property, related to the concept of Anderson or strong localization, is not straightforward to observe experimentally as in many systems the situation is made complex by interaction and decoherence effects. Ultracold atoms are very flexible systems, where the parasitic effects may be reduced; they are good candidates to observe strong localization if one is able to produce a strong enough disorder. It has been proposed to realize a controllable disorder for matter waves by randomly trapping atoms of another species at the nodes of an optical lattice, with a filling factor less than unity. For the matter wave the optical lattice is far detuned and is assumed to have a negligible mechanical effect. The matter wave then only sees the trapped species, which, in a regime of negligible tunneling, constitutes a static disordered potential of point-like scatterers [1]. We analyze the possibility to observe three-dimensional strong localization of matter waves with this realization of disorder [2]. We show that, provided one is able to adjust the effective scattering length of a trapped scatterer to a value close to the mean inter-scatterer separation d, one can produce localized states with a localization length as short as d, in practice in the micrometer range. We have obtained the value of the effective scattering length by solving the two-body problem of scattering of a free matter wave on a harmonically trapped atom. We predict confinement induced resonances, with an identified physical origin, that may be used to tune the effective scattering length to the desired value, in combination with an interspecies Feshbach resonance.

[1] U. Gavish, Y. Castin, Phys. Rev. Lett. 95, 020401 (2005).
[2] P. Massignan, Y. Castin, Phys. Rev. A 74, 013616 (2006).