Simulating quantum transport with atoms and light

Philippe Bouyer
Laboratoire Photonique, Numérique et Nanosciences, UMR5298 -LP2N, IOGS -CNRS –Université de Bordeaux
IOA – rue Francois Mitterand, 33400 TALENCE, France

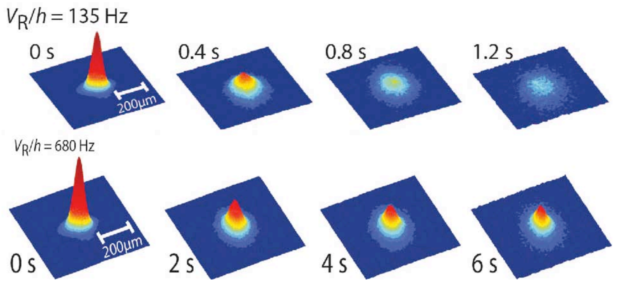

FIG. 1. Observation of localization in 3D with an expanding Bose-Einstein Condensate in the presence of a 3D speckle disorder. At low disorder (top), diffusion is observed. At higher disorder (bottom), a central feature remains even after very long diffusion times.

The transport of quantum particles in non ideal mate-rial media (eg the conduction of electrons in an imperfect crystal) is strongly affected by scattering from impurities of the medium. Even for a weak disorder, semi-classical theories, such as those based on the Boltzmann equation for matter-waves scattering from the impurities, often fail to describe transport properties and full quantum approaches are necessary. The properties of the quantum systems are of fundamental interest as they show intriguing and non-intuitive phenomena that are not yet fully understood such as Anderson localization, percolation, disorder-driven quantum phase transitions and the corresponding Bose-glass or spin-glass phases. Understanding quantum transport in amorphous solids is one of the main issues in this context, related to electric and thermal conductivities.

Ultracold atomic gases can now be considered to revisit the problem of quantum conductivity and quantum transport under unique control possibilities. Dilute atomic Bose-Einstein condensates (BEC) and degenerate Fermi gases (DFG) are produced routinely taking advantage of the recent progress in cooling and trapping of neutral atoms. Transport has been widely investigated in controlled potentials with no defects, for instance periodic potentials (optical lattices). Controlled disordered potentials can also be produced with various techniques such as the use of magnetic traps designed on atomic chips with rough wires, the use of localized impurity atoms, the use of radio-frequency fields or the use of optical potentials. This recently lead to the observation of the Anderson Localization of a BEC in 1D and 3D, and the study of diffusion properties during matter-wave transport.

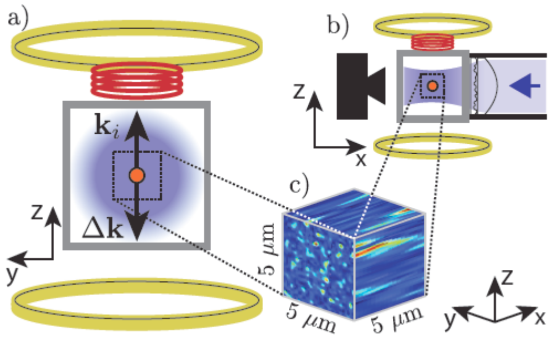

FIG. 2. Experimental Setup for studying quntum trqnsport with cold atoms. A cloud of ultracold atoms is launched upward, along the vertical z axis, with an initial momentum ~ki. The disordered potential is created by an anisotropic laser speckle elongated along the x axis (shaded blue), a 3D false color representation of which is shown in (c).Mmagnetic levitation, allowing for long evolution times, is realized by the pair of large coils (yellow).