Studying Anderson transitions with atomic matter waves

C. Hainaut[1], I. Manai[1], J.F. Clément[1], R. Chicireanu[1], P. Szriftgiser[1], and J.C. Garreau[1]

[1] *Laboratoire PhLAM, CNRS and University of Lille, F-59655, Villeneuve d'Ascq*

Presenting Author: isam.manai@univ-lille1.fr

In the presence of a disordered potential, the classical diffusive transport of a particle can be inhibited by quantum interference between the various paths where the particle is multiply scattered by disorder, a puzzling phenomenon known as Anderson localization [1]. The dimensionality of the system plays a major role, which can be understood qualitatively from the scaling theory of localization [2,3]. In dimension $d = 3$, there is delocalized-localized (or metal-insulator in solid state physics language) transition — known as the Anderson transition — with a mobility edge E_c separating localized motion at low energy (strong disorder) from diffusive motion at high energy (low disorder). On the localized side, the localization length ξ diverges algebraically $\xi(E) \propto (E_c - E)^{-\nu}$, with ν the critical exponent of the transition. On the diffusive side, the diffusion constant vanishes like $D(E) \propto (E - E_c)^s$ with, according to the scaling theory, $s = (d-2)\nu$ [3, 4].

A key prediction of the scaling theory is that the critical exponents are **universal**, that is do not depend on the microscopic details of the model used, such as the correlation functions of the disorder, the dispersion relation of the particles, etc. Numerical experiments on simple models [5, 6, 7] such as the tight-binding Anderson model, have confirmed this universality, with a non-trivial value of the critical exponent around $\nu = 1.57$ for spinless time-reversal invariant 3-dimensional (3D) systems [8]. However, there is a huge lack of experimental results in this area.

We experimentally test the universality of the Anderson three dimensional metal-insulator transition, using a quasiperiodic atomic kicked rotor [9]. Nine sets of parameters controlling the microscopic details have been tested. Our observation indicates that the transition is of second order, with a critical exponent independent of the microscopic details. We thus demonstrate that the value of the critical exponent is universal. the average value 1.63 ± 0.05 agrees very well with the numerically predicted value $\nu = 1.58$ [10].

More recently, we have modified our experimental setup to increase significantly the interaction time between cold atoms and the pulsed 1D optical lattice. It allows us to apply 1000 optical pulses on the cold atomic sample (6-fold improvement on maximum pulse number). One can thus extend soon our experimental study on Anderson model to higher dimensions (d = 4).

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