Graphene and cold atoms: when particles play with their mass

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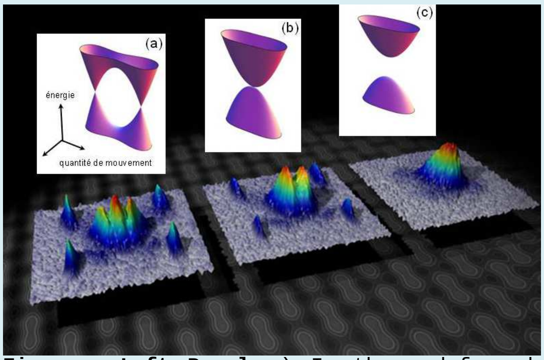
Recently, an experimental team (T. Esslinger in Zürich [1]) realized an ultracold gas of atoms moving in a potential landscape designed by laser fields to simulate an artificial graphene which can be manipulated and deformed at will. Atoms now play the role of electrons and laser fields that of the crystalline lattice. To probe the energy spectrum, the existence of Dirac points, their motion and their merging, they were able to accelerate a low energy cloud of Fermions. By measuring their evolution from low to high energy states (i.e. from the valence to the conduction band), they were able to probe the spectrum and the merging of the Dirac points. The results of the experiment were in perfect agreement with the theoretical predictions of the universal Hamiltonian developed in the theory group (see 1.1.1) [2]. Moreover, using the universal Hamiltonian, we were able to compute the probability for an atom to be transferred from one band to the other as a function of the direction of acceleration, and give a remarkable quantitative understanding of the experimental results [3]. This opens a vast field of new possibilities to probe the physics of “Dirac matter”.



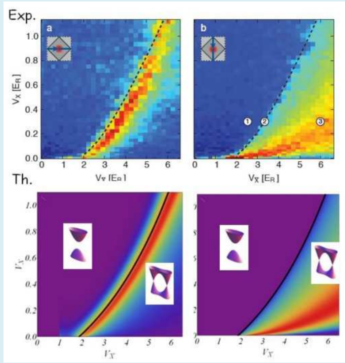


Figure : Left Panel a) In the undeformed lattice of cold atoms simulating graphene, the energy spectrum is that of massless particles with two « Dirac cones » : the energy is proportional to the momentum. c) In highly deformed lattice, the spectrum becomes massive. b) At the frontier between these two regimes, there is a finite mass in one direction but a vanishing one in the other. Experimental results for the transfer probability are shown below the corresponding energy spectrum. The central part represents the non-transfered proportion of atoms and the satellites the transferred proportion. **Right Panel** Top: probability for an atom to be transferred to the upper band, as a function of parameters of the optical lattice, for two directions of the acceleration, parallel or perpendicular to the direction of the cones. Bottom : the theory perfectly describes the experimental findings without external parameter.

References :

[1] Creating, moving and merging Dirac points with a Fermi gas in a tunable honeycomb lattice, L. Tarruell et al., Nature 483, 302 (2012)
[2] A universal Hamiltonian for the motion and the merging of Dirac cones in a 2D crystal, G. Montambaux, F. Piéchon, J.-N. Fuchs and M.O. Goerbig, Eur. Phys. J. B 72, 509 (2009)
[3] Bloch-Zener oscillations across a merging transition of Dirac points , L.-K. Lim, J.-N. Fuchs and G. Montambaux, Phys. Rev. Lett. 108, 175303 (2012).