Experimental Realization of the Haldane Model with Ultracold Atoms

Gregor Jotzu[1], Michael Messer[1], Rémi Desbuquois[1*], Martin Lebrat[1], Thomas Uehlinger[1], Daniel Greif[2], Tilman Esslinger[1]

[1]Institute for Quantum Electronics, ETH Zurich, Switzerland

[2]Department of Physics, Harvard University, USA

***Email of Presenting Author: desbuquois@phys.ethz.ch**

A topologically non-trivial band structure appears in a hexagonal lattice if time-reversal symmetry is broken, as suggested by F. D. M. Haldane. He further pointed out that, in combination with broken inversion symmetry, this gives rise to a phase diagram containing topologically distinct phases, yet without the necessity of a magnetic field. Studying the band structure of a hexagonal lattice with broken time reversal symmetry induced by complex valued next-nearest neighbour couplings, he showed that the boundaries of the topologically different phases are gap opening-and-closing transitions at the Dirac points. Whilst a realization of this model in a material was hardly conceivable, it provided the conceptual basis for other topological insulators and the quantum spin Hall effect. Prospects to realize the model with cold atoms emerged by advances in generating effective magnetic fields for neutral atoms and the idea to employ time-dependent fields to break time-reversal symmetry in a hexagonal lattice. Here we report on the implementation of the Haldane model in a periodically driven honeycomb optical lattice and the characterization of the topological Bloch bands using non-interacting fermionic atoms. Modulating the position of the lattice sites along a circular trajectory generates complex next-nearest-neighbour tunnelling and a gap opens at the Dirac points, which we measure using momentum-resolved inter-band transitions. In analogy to a Hall conductance we observe a characteristic displacement of the atomic cloud under a constant force. By additionally breaking the inversion-symmetry, we identify the closing of the gap at an individual Dirac point, associated with the transition between the topologically distinct phases, obtaining good agreement with the calculated phase diagram. Whilst the physics of the non-interacting system is determined by the single-particle band structure, as studied in this work, the cold atom systems is also suited to explore the interplay between topology and interactions.