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Topological phases in the zeroth Landau level of bilayer graphene

ZLATKO PAPIC, Perimeter Institute

Over the past years, a remarkable variety of novel correlated states was discovered in graphene and its bilayer in a magnetic field. These states exhibit previously unseen richness due to an interplay of electron spin, valley and orbital degrees of freedom. They are furthermore distinguished by their high degree of tunability, e.g. via the in-plane magnetic or the perpendicular electric field, which allows one to probe their properties in a more flexible and direct way than in GaAs semiconductor systems. In this talk I will present a theoretical overview of the phase diagram of the partially-filled zeroth Landau level of bilayer graphene. Using realistic large-scale numerical calculations [1] that incorporate strong mixing between orbitally degenerate sublevels, as well as the screening of the Coulomb interaction, we identify several robust quantum Hall states with odd denominators such as $\nu = -4/3, -5/3, -8/5$. Although these states bear some relation to their more familiar analogs in GaAs, their collective excitations are expected to be different, as we illustrate on an example of the $\nu = -1$ state that acquires a neutral gap in bilayer graphene. Furthermore, we find evidence for the existence of an incompressible, even-denominator $\nu = -1/2$ state, and argue that this state is in the universality class of the non-Abelian Moore-Read state or its particle-hole conjugate, while other candidates such as the 331 state are unlikely to describe it. Finally, it will be shown that symmetry breaking, induced by an electric field applied perpendicular to the basal plane, is a useful experimental knob to tune the quantum phase transitions between integer or fractional states in bilayer graphene at a fixed filling factor [2]. These results illustrate the potential of bilayer graphene as a model platform to study the emergent topologically ordered phases and transitions between them via symmetry breaking.

[1] Z. Papic and D. Abanin, Phys. Rev. Lett. 112, 046602 (2014).

[2] Patrick Maher, Lei Wang, Yuanda Gao, Carlos Forsythe, Takashi Taniguchi, Kenji Watanabe, Dmitry Abanin, Zlatko Papic, Paul Cadden-Zimansky, James Hone, Philip Kim, and Cory R. Dean, Science 345, 61-64 (2014).