Dirac fermions, Chern numbers and bulk-edge correspondence in graphene with randomness

Y. Hatsugai
Institute of Physics, University of Tsukuba, Tsukuba, 305-8571 Japan

Massless Dirac fermions which are experimentally realized in graphene have rather long history. We focus on their topological properties and symmetry in this talk. A zero gap semiconductor implies that the effective low energy Hamiltonian has a chiral symmetry. On the contrary, the chiral symmetry of the crystal implies topologically protected doubling of Dirac cones. It is a two-dimensional analogue of the Nielsen-Ninomiya theorem in four-dimensions [1]. This chiral symmetry plays important roles in many aspects of graphene such as the anomalous quantum Hall effect and the boundary physics. By the bulk-edge correspondence, it implies that the boundary physics of graphene reflects non-trivial topological structure of the bulk and has to be rich [2]. Actually an appearance of characteristic edge states is confirmed even experimentally. As is well known, the chiral symmetry also plays a fundamental role in the Anderson localization. We have numerically demonstrated crucial roles of the chiral symmetry in graphene with a stress on its spatial correlation of the bond/gauge disorder. It may be a good model for ripples of a free standing single layer graphene. Especially for the N=0 Landau level where special role of the zero energy is apparent since the chiral symmetry implies a particle-hole symmetry of the spectrum. Only when the special correlation of the bond disorder exceeds lattice spacing, the N=0 Landau level is extremely sharp even with the chiral symmetric disorder, which is consistent with the index theorem prediction [3, 4].

The Hall conductance of the graphene that is given by the sum of the Chern numbers of filled Landu levels inevitably includes contribution of Dirac sea. It brings numerical difficulty in calculation of each Chern number separately especially for disordered graphene. Then use of the non-Abelian Berry connection defined by a multiplet of the filled Landau levels is essential for the consistent calculation. We have demonstrated numerical validity of the non-Abelian Berry connection [1,3,4]. Effects of the next nearest neighbor hopping, which does not respect a naive chiral symmetry is discussed as well [4]. The work has been done in collaboration with T. Kawarabayashi T. Morimoto and H. Aoki.

References

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