Emergence of massless Dirac electrons in graphene and related materials

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We review recent theoretical studies on the emergence of massless Dirac electrons in graphene and related materials. The band structure of graphene monolayer is equivalent to a relativistic massless particle where the conduction band and valence band with linear dispersion touch each other at the so-called Dirac point [1]. The band touching at the Dirac point is protected by the time-reversal symmetry and the space inversion symmetry [2], and it is robust against perturbations unless either symmetry is broken. In a graphene multilayer composed of two or more graphene layers, the interlayer coupling drastically changes the band structure in a manner depending on the number of layers and the stacking configuration. Nevertheless the band touching and the Dirac-spectrum appear when the lattice structure has the space inversion symmetry, such as in ABA-stacked even-layered graphenes, and also in arbitrary ABC-stacked graphenes [3,4].

A massless Dirac spectrum can also occur for different symmetrical reason. Our recent study [5] shows that the ABA-stacked odd-layered graphene with a perpendicular gate electric field exhibits a number of emergent Dirac cones touching at zero energy, even though the system obviously lacks the special inversion symmetry. The band-touching points are then protected by the chiral symmetry hidden in the Hamiltonian.

The Dirac point is a singular point in k-space around which the Berry phase rotates by angle pi. This singularity is closely related to the emergence of the edge modes which is localized to the boundary of the system [6]. In the multi Dirac cone system mentioned above, we show that the edge state channels appear to connect different Dirac points, and then the system exhibits a nontrivial valley Hall state where chiral edge modes propagating in opposite directions between two valleys (K, K') in Brillouin zone [5].

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