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ON THE ORIGIN OF MINIMAL CONDUCTIVITY AT A BAND CROSSING

The physics of massless relativistic quantum particles has recently arisen in the electronic properties of solids following the discovery of graphene. Around the accidental crossing of two energy bands, the electronic excitations are described by a Weyl equation initially derived for ultra-relativistic particles. Similar three and four band semimetals have recently been discovered in two and three dimensions [1; 2].

Among the remarkable features of graphene is the existence of a finite minimal conductivity at the band crossing where the electronic density vanishes [3; 4]. Whereas one naively expect no transport to occur due to the absence of propagating wave states, evanescent states do give rise to a finite conductivity in a confined geometry. To characterize semimetallic phases beyond graphene the question of the origin of this minimal conductivity has to be adressed. The minimal conductivity at the band crossing was associated to the Zitterbewegung of Dirac particles, an intrinsic agitation characteristic of ultra relativistic particles which leads to diffusive motion even in perfectly clean samples [5; 6]. However, whether the presence of Zitterbewegung is sufficient or other constraints are required to infer a finite minimal conductivity is an open question. Among the properties naturally present in graphene at low energy are a chiral symmetry, a pseudo-spin structure and a quantized Berry phase acquired by an electron when winding around the crossing point. The latter also gives rise to another two remarkable phenomena: the anomalous quantum Hall effect and the topological robustness of graphene.

In [7], we investigate the origin of the minimal conductivity at the band crossing by considering three-band extensions of graphene. To that end we study the transport properties of wide junctions using both analytical and numerical Landauer approaches (see figure). Numerical calculations were performed using the KWANT code [8].

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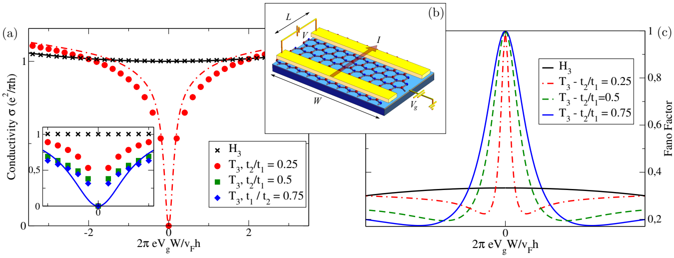

Figure : Conductivity (a) and Fano factor (c) as a function of a gate potential V_g applied to the sample in the geometry represented in (b). The data points are obtained using the KWANT code [8] while the curves were computed analytically.

We demonstrate that neither chiral symmetry nor pseudo-spin structure, nor Zitterbewegung are at the origin of the finite minimal conductivity. On the other hand, at least for the three-bands models with chiral symmetry, we relate the non vanishing minimal conductivity with the existence of topological Berry phases.

This result highlights a new connection between the nature of evanescent states (and associated minimal conductivity) and a topological property (topological Berry phase) of wave-like eigenstates. This evanescent-bulk states correspondence is reminiscent of the standard bulk-edge correspondence in topological insulating phases. Here, the non-vanishing conductivity through evanescent states and the quantized Berry phase of Bloch states both follow from lattice properties encoded into a duality property (so called class $\mathcal{D}_{\mathrm{I}}$), in contrast with a symmetry property. Generically, the special lattice properties required to belong the duality class $\mathcal{D}_{\mathrm{I}}$ are not met. In that case the Berry phase is not quantized and the conductivity vanishes at the band crossing. This puts in perspective the existence of a minimal conductivity in graphene that turns out to fulfill a very special criteria. Our results open a new route to a fine probe of band crossings through evanescent states that discriminates different fundamental transport properties (conductivity, noise) of semimetals.

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