

Band touching from real space topology in frustrated hopping models

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“Accidental” band touchings, such as the Dirac point in graphene, can be protected by topology. Many cases similar to graphene exist, and are well understood to arise from the momentum space topology of Bloch states. A different situation arises in “frustrated” hopping models, in which at least one energy band, at the maximum or minimum of the spectrum, is dispersionless. The states of the flat band(s) can be represented in a basis which is fully localized, having support on a vanishing fraction of the system in the thermodynamic limit. In the majority of examples, a dispersive band touches the flat band(s) at a number of discrete points in momentum space. We demonstrate that this band touching is related to states which exhibit non-trivial topology in *real space*. Specifically, these states have support on one-dimensional loops which wind around the entire system (with periodic boundary conditions). A counting argument is given that determines, in each case, whether there is band touching or not, in precise correspondence to the result of straightforward diagonalization. When they are present, the topological structure protects the band touchings in the sense that they can only be removed by perturbations which *also* split the degeneracy of the flat band.