Quantum distance and anomalous Landau levels of flat bands

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Abstract

Since the recent discovery of the superconductivity in the twisted bilayer graphene, flat band systems have been studied intensively. We uncover the novel roles of the band-crossing singularities in flat bands. While the singularity of the flat band is topologically trivial, it can be characterized by a pseudo-spin canting around the touching point. We propose that the strength of the singularity is defined as the maximum canting angle between two pseudo-spins, or equivalently, the maximum quantum distance between two Bloch wave functions. This bulk's singularity guarantees the existence of two topological objects in real space, one is the non-contractible loop state under the periodic boundary condition, and the other is the robust boundary modes under the open boundary condition. Then, we show that when the flat band has a singularity, its Landau levels develop in the energy gap contradicting to the Onsager's semiclassical quantization rule, and their spreading into the gap is determined by the maximum quantum distance around the band crossing point. This is a new rule for the Landau level quantization, and completely beyond the conventional semiclassical paradigm. Moreover, the Landau levels corresponding to the flat band exhibit 1/n dependence, where n is the Landau level index. This behavior leads to the divergence of the orbital magnetic susceptibilities.