Emergent Quasiparticles in 2D Materials

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Material's geometrical structure is a fundamental part of their properties. For instance, the space-group symmetries dictate the energy degeneracy of quasiparticles (e.g., electronic, photonic) in crystalline structures. For spinless systems, there can only be double or triple degeneracies protected by these symmetries, while other degeneracies are usually taken as accidental. Although the space group can predict the 2-fold degeneracy of the Dirac cone on the honeycomb structure in graphene, and the 2-fold degeneracy of a dispersive and a flat band in the Kagome structure, it cannot by itself predict the pseudospin-1 Dirac dispersion in the Lieb lattice. In this work we show that it is possible to define higher degeneracies design principles exploring site permutation symmetries. These design principles are shown to be satisfied in previously studied lattices, and new structures are proposed with three, four, and five degeneracy points for spinless systems. Although these features seem to be particular for a few 2D systems rather than common, given this correlation between structure and properties, exploring new geometries can lead to unexplored states and phenomena. We therefore characterize 1255 lattices composed of k-uniform tiling of the Euclidean plane and unveil their intrinsic properties; this class of arranged tiles presents high-degeneracy points, exotic quasiparticles, and flat bands as common features.