Fully symmetric and non-fractionalized Mott insulators at fractional site-filling

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Within the Landau paradigm, phases of matter are distinguished by spontaneous symmetry breaking. Implicit here is the assumption that a completely symmetric state exists: a paramagnet. At zero temperature such quantum featureless insulators may be forbidden, triggering either conventional order or topological order with fractionalized excitations. Such is the case for interacting particles when the particle number per unit cell, f, is not an integer. But, can lattice symmetries forbid featureless insulators even at integer f?

First we show that featureless insulators of bosons can be constructed via fermionic band insulators which admit symmetric exponentially localized Wannier orbitals. We explicitly write such Wannier permanents wavefunctions and parent Hamiltonians on the f=1/3 kagome lattice, where they are relevant to cold atom experiments and also yield 1/3 magnetization plateau states for spin models in an applied field. We then turn to cases when the fermion band insulator to boson Mott insulator mechanism fails.

An especially relevant case is the honeycomb (graphene) lattice --- where free spinless fermions at f=1 (the two sites per unit cell mean f=1 is half filling per site) are always metallic. Here we present wave functions for bosons, and a related spin-singlet wave function for spinful electrons, on the f=1 honeycomb, and demonstrate via quantum to classical mappings that they do form featureless Mott insulators. The construction generalizes to symmorphic lattices at integer f in any dimension. Our results explicitly demonstrate that in these cases, despite the absence of a non-interacting insulator at the same filling, lack of order at zero temperature does not imply fractionalization.