Moiré Materials

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When a moiré pattern is formed between two-dimensional crystals that are semiconductors or semimetals, low energy electronic states are described by an emergent Hamiltonian that is periodic, effectively realizing artificial two-dimensional crystals that have lattice constants on the 10 nm length scale. The lattice constants are large enough that field effects can be used to vary the number of electrons per effective atom by more than one, allowing periodic tables to be explored experimentally without chemical disorder. Moiré material Hamiltonians can be determined phenomenologically [1] or derived [2] from lattice-scale DFT calculations. In recent years these moiré materials have proven to be a truly amazing platform for new physics, particularly physics in which strong electronic correlations and topology combine in new ways. In the case of graphene-multilayer-based moiré materials [1], non-trivial topology is inherited from the Dirac points of the individual graphene sheets, whereas in the case of parallel-stacked transition metal dichalcogenide layers [3, 4] it emerges serendipitously from the coupling between layers. I will discuss the ordinary and anomalous integer and fractional quantum Hall effects in both established classes of moiré materials and speculate on new classes in which this property-engineering strategy might equally effective.

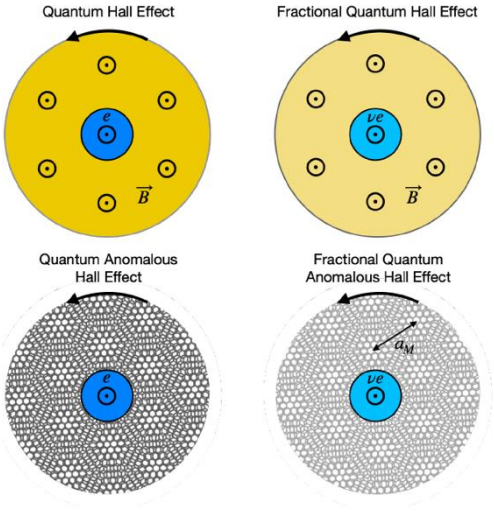

Fig. 1. Moiré materials host all four quantum Hall effects, integer and fractional effects both anomalous and in the presence of a magnetic field. All four quantum Hall effects produce dissipation less chiral edge currents, and the fractional effects produce quasiparticles with fractional charge. (After Nature Reviews Physics 6, 349–351(2024).)

References:

[1] Rafi Bistritzer and Allan H MacDonald. MoirÅLe bands in twisted double-layer graphene. Proceedings of the National Academy of Sciences, **108**, 1223 (2011).

[2] Jeil Jung, Arnaud Raoux, Zhenhua Qiao, and Allan H MacDonald. Ab initio theory of moiré superlattice bands in layered two-dimensional materials. Physical Review B, **89**, 205414 (2014).

[3] Fengcheng Wu, Timothy Lovorn, Emanuel Tutuc, and Allan H MacDonald. Hubbard model physics in transition metal dichalcogenide moirÅLe bands. Phys. Rev. Lett. 121, 026402 (2018).

[4] Fengcheng Wu, Timothy Lovorn, Emanuel Tutuc, Ivar Martin, and AH MacDonald. Topological insulators in twisted transition metal dichalcogenide homobilayers. Phys. Rev. Lett., **122**, 086402 (2019).