Quantization and Quantum Oscillations of Sublattice Charge Order in Dirac Insulators

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We report the quantization, quantum oscillations, and singular behavior of sublattice symmetry-breaking sublattice charge order (SCO) in two-dimensional Dirac insulators at charge neutrality under perpendicular magnetic fields B. SCO is induced by staggered sublattice potentials, such as those originating from substrates, strains, hydrogenation, and chemical doping. In small non-quantizing magnetic fields that result in less than a flux quantum threading the system, and small sublattice symmetry breaking potentials, SCO exhibits perturbative singular magnetic field dependence, $\sim |B|$, originating from hopping between neighboring sites of the same sublattice. At intermediate magnetic fields, when the cyclotron gap between the zeroth Landau level and the first Landau level, ω_c, is smaller than the sublattice potential, $\omega_c \lesssim \Delta$, SCO shows *universally* quantized plateaus owing to discrete Landau-level degeneracy. As the magnetic flux increases by one flux quantum, one electron (per spin) is transferred from the sublattice with a higher chemical potential to the sublattice with a lower chemical potential. One electron transfer between sublattices per flux quantum results from the sublattice polarization of the zeroth Landau level in gapped Dirac materials, realizing the topological Thouless pump effect. At stronger magnetic fields, $\omega_c \gtrsim \Delta$, corresponding to integer quantum Hall regimes, SCO displays singularities based on the physics of quantum magneto-oscillations. Our findings suggest new ways to experimentally detect the presence of the energy gap in Dirac materials, irrespective of the gap size.