Optical spectroscopy of electronic Wigner crystals

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Electronic Wigner crystals are quantum solids that emerge when electrons arrange into a lattice due to dominant Coulomb repulsion. In monolayer transition metal dichalcogenides, the combination of low dimensionality and reduced dielectric screening greatly enhances many-body interactions, enabling the realization of these crystalline electron phases at experimentally accessible carrier densities and temperatures. The Umklapp scattering of excitons, manifested in optical spectroscopy as an additional high-energy spectral peak that arises when excitons scatter off the reciprocal lattice of the Wigner crystal, provides a clear, direct signature of electron crystallization.

Here we investigate the emergence and evolution of Wigner crystals as a function of carrier concentration through optical spectroscopy of Umklapp scattering in two types of samples: monolayer WSe_2 and a $MoSe_2$ - WSe_2 moiré device. In monolayer WSe_2, we observe the formation of Wigner crystals at low carrier density and track their evolution into microemulsion phases and putative spin-liquid behavior at higher doping. Strikingly, in the presence of a moiré potential, Wigner crystals appear at rational fractional fillings, yet persist continuously between commensurate densities, confirming that Coulomb interactions outweigh the moiré potential. These results illustrate the power of optical spectroscopy in probing strongly correlated electrons, reveal the rich phase diagram of electronic crystals, and highlight the crucial interplay between electron-electron interactions and engineered periodic potentials.