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Title: Shubnikov-de Haas oscillations in optical conductivity of monolayer $MoSe_2$

Abstract:

Atomically thin transition metal dichalcogenides (TMD) exhibit a unique combination of extraordinary properties, including valley-contrasting optical response, ultralarge exciton binding energies, and strong exciton-carrier interactions, which make them a promising platform for exploration of condensed matter physics. In parallel, owing to large carrier effective masses, TMD monolayers feature low cyclotron energies, which together with spin-valley locking and finite Berry curvature give rise to a unique structure of spin-valley polarized Landau levels (LLs) that has been recently demonstrated in several transport studies [1-4]. However, to date, the optical signatures of such LLs have been uncovered only for large electron densities [5], where exciton binding is strongly reduced, resulting in the presence of band-to-band inter-LL transitions in the absorption spectrum. Here we report polarization-resolved resonant reflection of a spin-valley polarized hole system in a charge-tunable $MoSe_2$ monolayer subjected to a strong magnetic field in the opposite limit of low hole densities $P < 3 \cdot 10^{12}\ \mathrm{cm}^{-2}$, where the exciton remains tightly bound [6]. We show that the strength of exciton-hole interactions in such a dilute regime is sensitively dependent on the occupation of hole LLs, giving rise to a pronounced, hole-density-dependent Shubnikov-de Haas-like oscillations in the energy and linewidth of the excitonic resonances. These oscillations are found to be precisely correlated with LL filling factor, which constitutes a first direct evidence for the influence of integer quantum-Hall states on the excitonic excitations in a TMD monolayer. The interaction-enabled optical access to the quantum-Hall physics that we demonstrate paves the way towards optical investigation of a rich field of strongly correlated phenomena at integer and fractional filling factors in atomically thin semiconductors.

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