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Transport anomalies of high-mobility Q-valley electrons in few-layer WS2 and MoS2[1]

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Atomically thin transition metal dichalcogenides (TMDCs) have opened new avenues for exploring physical property anomalies due to their large band gaps, strong spin-orbit couplings, and rich valley degrees of freedom. Although novel optical phenomena such as valley selective circular dichroism, opto-valley Hall effect, and valley Zeeman effect have been extensively studied in TMDCs, investigation of quantum transport properties has encountered a number of obstacles primarily due to the low carrier mobility and strong impurity scattering. Recently, we successfully fabricated ultrahigh-mobility few-layer TMDC field-effect transistors based on the boron nitride encapsulation method and observed a number of interesting transport properties, such as even-odd layer-dependent magnetotransport of Q-valley electrons in WS2 and MoS2 and unconventional quantum Hall transport of Γ-valley hole carriers in WSe2. In few-layer samples of these TMDCs, the conduction bands along the ΓK directions shift downward energetically in the presence of interlayer interactions, forming six Q-valleys related by three-fold rotational symmetry and time reversal symmetry. In even-layers the extra inversion symmetry requires all states to be Kramers degenerate, whereas in odd-layers the intrinsic inversion asymmetry dictates the Q-valleys to be spin-valley coupled. In this talk, I'll demonstrate the prominent Shubnikov-de Hass (SdH) oscillations and the observation of the onset of quantum Hall plateaus for the Q-valley electrons. Universally in the SdH oscillations, we observe a valley Zeeman effect in all odd-layer TMDC devices and a spin Zeeman effect in all even-layer TMDC devices. In addition, we observe a series of quantum Hall states following an unconventional sequence predominated by odd-integer states under a moderate strength magnetic field in p-type few-layer TMDCs, indicating a large Zeeman energy associated with the carriers in the valence band at the Γ-valley.

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