Valley selective Zeeman effect in monolayer transition metal dichalcogenides

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Monolayer transition metal dichalcogenides (TMDs) have recently emerged as a new class of direct bandgap 2D semiconductors. Like graphene, TMDs have a honeycomb lattice with extrema at the K and –K in the Brillouin zone, but with a non-zero bandgap. As a result of the broken inversion symmetry in a monolayer (ML), this valley degree of freedom can be selectively accessed by optical helicity. At zero magnetic field, the two valleys are degenerate, however, their corresponding magnetic moments have opposite signs. In this work, we experimentally investigate the ability of a magnetic field to selectively tune the valley energies in ML $MoSe_2$ [1] and WSe_2 by circularly polarized high field magneto-photoluminescence (magneto-PL) spectroscopy.

$MoSe_2$ and WSe_2 MLs were fabricated by mechanical exfoliation on to a SiO_2/Si substrate. PL measurements were performed using 2.33eV laser excitation and magnetic fields up to 31T. The low-temperature PL spectra of monolayer $MoSe_2$ are dominated by two peaks corresponding to the emission from neutral (X^0) and charged ($X^{\pm}$) excitons. At low carrier density, the PL energies of both peaks experience a linear shift of $\approx 2\mu_B$/T in a perpendicular magnetic field. The direction of the shift is reversed for photons with opposite circular polarization, clearly demonstrating the lifting of the valley degeneracy due to the contribution of atomic orbital moments of the Mo atoms [1]. This is further confirmed by measurements in parallel field, where no such splitting occurs. At very high doping, the Zeeman shift of the charged exitons (trions) increases by about 50% compared to the low doping case. Qualitatively, the increase of the shift is consistent with the recombination of intervalley trions when the Fermi level is moved into the conduction band. We observe similar shifts of the X^0 and X^- PL energies in ML WSe_2, indicating that the valley Zeeman splitting is fundamental to all semiconducting ML TMDs. However, we observe an opposite change of the X^- PL intensity with the magnetic field, which may indicate another configuration for the ground state trion in WSe_2.

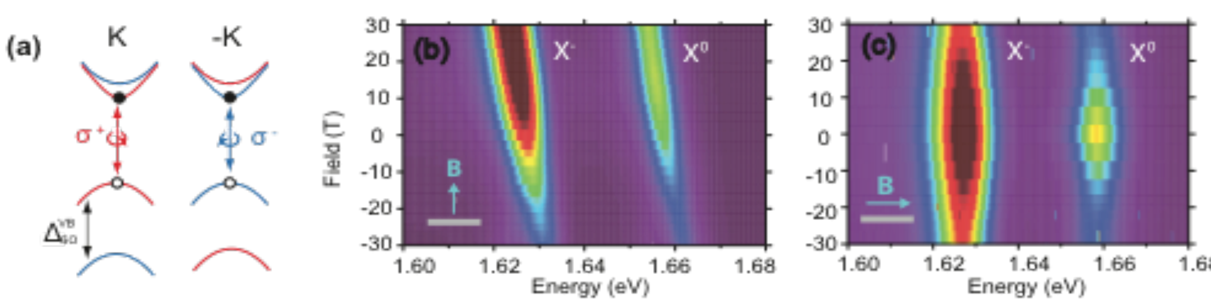

Figure 1 (a) Band diagram of monolayer $MoSe_2$ at zero magnetic field. Red (blue) colors refer to spin up (down) bands. (b, c) Magneto-PL of $MoSe_2$ as a function of an (b) out-of-plane (c) in-plane magnetic field at 5K.

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