Valley Splitting and Polarization by the Zeeman Effect in Monolayer $MoSe_2$

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Introduction

Monolayer $MoSe_2$ crystals feature two inequivalent valleys at the K and K' points of its Brillouin zone. Since the valleys are linked by time-reversal symmetry, they are energetically degenerate, while the magnetic moments of the corresponding valley states are of the same magnitude, but have opposite sign. Coupling to the valley magnetic moments by a magnetic field thus presents new opportunities for the study of the fundamental physical properties of the valley electronic states, as well as for the development of new approaches to valleytronic control.

Experimental

The monolayer $MoSe_2$ samples were prepared by mechanical exfoliation of the bulk crystal. To study the magnetic response of the valleys in these monolayers, we measured their photoluminescence (PL) spectrum in the presence of an out-of-plane magnetic field. The measurements were performed using a micro-PL optical probe and the superconducting magnet in cell #3.

Results and Discussion

Our main result is summarized in Fig. 1. Here we present PL spectral maps from a monolayer $MoSe_2$ crystal with a perpendicular magnetic field varying from -10 T to +10 T. The two peaks in the PL spectra correspond to emission from neutral and charged excitons, with the neutral exciton emission lying at higher energy. The two panels correspond to the detection of two different circular polarization states, arising, respectively, from the K and K' valleys in the Brillouin zone. [1] The PL energies of the two peaks shift linearly with the magnetic field and the direction of the shifts is reversed for photons with opposite circular polarization states. The linear shift corresponds to the Zeeman effect on the interband transition energy. The reversal of the shift direction demonstrates the breaking of valley degeneracy at finite magnetic field.

In addition to the shift in the peak energies, we also observe in Fig. 1 a monotonic variation in the relative intensities of the charged and neutral exciton with magnetic field, with opposite trend for emission from the two valleys. Since the relative intensity of the two exciton species is an indicator of charge density in the valleys, the valley dependent variation of the relative intensity shows that an imbalance in charge density in the two valleys, i.e. valley polarization, has been produced.

Conclusions

Through measurements of circularly polarized photoluminescence from neutral and charged excitons in $MoSe_2$, we have demonstrated the lifting of the K/K' valley degeneracy by a magnetic field and also the creation of valley polarization. These studies provide understanding of spin-valley physics in monolayer transition metal dichalcogenides. The paper reporting these findings will appear soon in Physical Review Letters [2].

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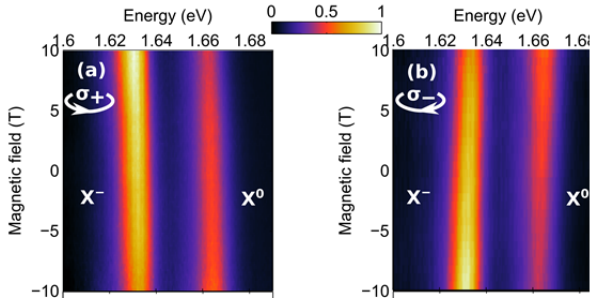

Figure 1. False color representation of the σ_+ (a) and σ_- (b) circularly polarized PL spectra for monolayer $MoSe_2$ in the low-doping regime as a function of the strength of the applied perpendicular magnetic field.

References

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[2] Li, Y. et al., Phys. Rev. Lett. (in press).