Magneto-luminescence emission from excited Rydberg states of 1L-WSe$_2$

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Introduction

The excitons in monolayer (1L) transition metal dichalcogenides (TMDCs) are interesting valleytronic entities that manifest strong Coulomb direct and exchange interactions. Similar to a hydrogen atom, the ground and excited bound states of excitons form the Rydberg series. While the 1s luminescence is ubiquitously observed and widely studied, higher energy excited states are much more challenging to access as a result of the Kasha's rule. Our group has fabricated ultrahigh quality 1L-WSe$_2$ that produces very narrow exciton emission peaks. At zero magnetic fields, we also successfully observe the 2s exciton emission, which remarkably exhibits much higher valley polarization than the 1s exciton (manuscript under review). We have studied these high-quality samples in NHMFL and found that we can observe luminescence emission up to the 4s excited states!

Experimental

The measurements were performed in NHMFL using the 31 Tesla magnet facility (cell 9) with a top loading cryostat. Optical access is achieved using an optical fiber system mounted inside the cryostat. We excite the sample with a 532nm laser light that is linearly polarized and collect the left circularly polarized luminescence emission as a function of the magnetic field.

Results and Discussion

Figure 1a shows a typical luminescence spectra at ±31Tesla. We observe a doublet structure for 1s to 4s excitons. The splitting is a result of Zeeman effect because the excitons in the K and K' valleys have opposite magnetic dipole moment. The Zeeman shift is linear in magnetic field B. From the field dependent emission in Fig.1b, it is clear that there is an additional nonlinear contribution, especially for 2s, 3s and 4s. We attribute this additional contribution to the diamagnetic shift. The response of the exciton energy to magnetic field is then written as:

$$E(B) = E(B=0)\text{-}(\mu_c\text{-}\mu_v)B + \frac{e^2}{8m_r}r^2B^2 \qquad [1].$$

We found Eq.[1] describes our results well; see fittings in Fig.1c for the energy difference of each doublet which gives the Zeeman splitting, and Fig.1d for the average energy that gives the diamagnetic shift.

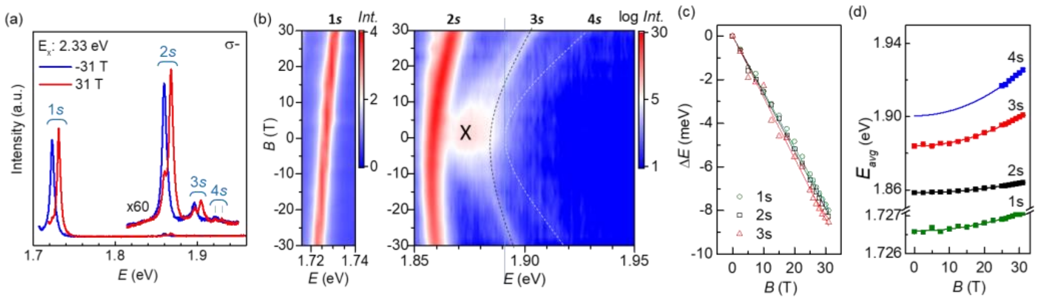

Fig.1 (a) Magneto-luminescence spectra at ±31Tesla. (b) 2D plot of the magneto-luminescence. (c) Zeeman shift and (d) diamagnetic shift of the exciton Rydberg states.

Conclusions

In conclusion, we experimentally observe up to the 4s exciton in 1L-WSe$_2$ in a strong magnetic field. The K and K' excitons split and their energy difference gives the Zeeman shift. We also determine the diamagnetic shift of the excitons which provides information on the sizes of the different exciton species.

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References

[1] Chen, S.-Y., *et al.*, manuscript under preparation, (2017).