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Investigating atomically thin materials with huge magnets

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Optical spectroscopy in high magnetic fields has historically played an essential role in determining the fundamental properties of excitons (mass, size, binding energy (EB) etc.). In conventional bulk semiconductors such as GaAs, or CuO_2, magnetic fields ~ 10T are sufficient to achieve the regime where cyclotron energies exceed EB. In marked contrast, in the family of monolayer semiconductors such as MoS_2, WSe_2 or 2D perovskites, masses are heavier and EB is huge, requiring magnetic fields of order 100 T to reach this regime [1,2,3].

In this talk, I will review our recent progress on magneto optical spectroscopy of laterally small and atomically thin materials in magnetic fields up to 91 T with an emphasis on the spin-valley physics of neutral and charged excitons.

In monolayer semiconductors at charge neutrality, high field magneto-spectroscopy revealed the diamagnetic shifts of the exciton Rydberg states [2,3], which allowed the first direct experimental measure of the excitons reduced mass and binding energy.

Surprisingly, utilizing nominally the same samples but now investigating the photoluminescence, we observe the emergence of a new excitonic peak from the neutral A:1s exciton in WSe_2, which we discuss in the framework of the theoretically predicted linear dispersing exciton branch originating from exchange interactions [4].

For heterostructures of a 2D semiconductor with graphene, we find a new multi-step proximity effect due to the crystalline nature of the stacked materials, where we show that careful investigation of the spin-valley physics can be used as a tool to quantify interlayer hybridization [5].

If time permits, I will show how high field spectroscopy revealed the intricate level structure of deterministically formed single atomic defects in 2D materials [6], which constitutes the ultimate limit of nanotechnology. We show how excitonic effects must be taken into account in order to understand quantum emitters in 2D materials, a result of importance for the field of quantum sensing and technology.

[1] A.V. Stier et al., Nature Comm. **7**, 10643 (2016).
[2] A.V. Stier et al., Phys. Rev. Lett **120**, 057405 (2018).
[3] M. Goryca et al., Nature Comm. **10**, 1 (2019).
[4] A. Delhomme et al., in prep. (2024).
[5] P. E. F. Junior et al., 2D Materials **10**, 034002 (2023).
[6] A. Hötger et al., npj 2D Mat. and Appl., **7**, 30 (2023).