DEPARTMENT OF PHYSICS & ASTRONOMY

CONDENSED MATTER SEMINAR

John Lupton

Department of Physics
University of Regensburg

Excitons with Negative-Mass Electrons

To anyone acquainted with elements of molecular spectroscopy, much of the activity in the budding field of optoelectronics of 2D crystal monolayers of transition-metal dichalcogenides such as MoS_2 sounds familiar. Even Andre Geim famously noted in 2005 that exfoliated crystals are basically just "giant molecules".
But there are a few differences worth noting: first and foremost, electronic delocalization in two dimensions is enormous, so that optical transitions gain giant oscillator strength. In fact, radiative rates become comparable to those of nanoparticle plasmons – allowing excitation energy to be harvested from the metal to the semiconductor [1].

An intriguing feature of molecules is that, under certain conditions, non-radiative dissipation by internal conversion is blocked, so that metastable bright excitons with energies far above the optical gap are formed [2]. In a semiconductor, such an exciton would entail an electron in a higher-lying conduction band – and indeed, light from such an exciton can be observed in a monolayer crystal, with a transition energy of almost twice the bandgap.

The difference to molecules lies in the role of momentum space. The curvature of upper conduction bands can be negative, giving the electron negative effective mass. The spectrum of radiative exciton recombination then acquires a striking phonon progression as the electron relaxes down in energy, emitting phonons. Luminescence from high-lying excitons in 2D semiconductors features a Franck-Condon progression identical to that of molecules.

Excitons in two-dimensional semiconductors have large binding energies. Because of the formation of metastable higher-lying excitons, the excitonic system can be thought of as a quasi-atomic three-level system. Quantum interference can arise between discrete excitonic transitions, leading to electromagnetically induced transparency [3]. Since the binding energy can be tuned in twisted bilayers [4], a new avenue for control of quantum-optical phenomena in the solid state opens up.

[1] Puchert et al., Nature Nano. 12, 637 (2017).
[2] Chaudhuri et al., Angew. Chem. Int. Ed. 52, 13449 (2013).
[3] Lin et al., Nature Phys. 15, 242 (2019).
[4] Merkl et al., Nature Mater. 18, 691 (2019).

Tuesday, September 3, 2019
4:00 pm, JFB 334
Refreshments will be served in JFB 334 at 3:45 pm