Optical properties of atomically thin semiconductors layers and heterostructures

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We discuss recent advances in our understanding of the optical properties of monolayers of the transition metal dichalcogenide (TMDC) materials, including MoS_2, $MoSe_2$, $MoTe_2$, WS_2, and WSe_2. These materials share several unusual characteristics, including a transition from an indirect-gap material in the bulk to a direct-gap, emissive material at monolayer thickness. They also exhibit selectivity to excitation of the degenerate K or K' valley under circularly polarized radiation.

In this paper, we highlight progress in understanding two types of interactions in these materials: the many-body interactions between charge carriers in one layer and interactions between carriers that arise when two monolayer sheets of materials stacked on one another to form a bilayer.

The many-body electronic interactions in monolayer TMDC crystals play a central role in defining their optical properties. Here we will stress recent spectroscopic studies in which we have identified the progression of excited exciton states in precise absorption measurements. This study directly reveals exciton binding energies of several hundred meV. A strongly non-hydrogenic disposition of levels is also observed. The strength of Coulomb interactions is also manifest in high-order excitonic states, including the three-body trion (or charged excitons) and the recently observed four-body biexcitons. Also of note is the possibility of modifying the many-body interactions through carrier doping or through the presence of high densities of excitation.

Another unusual type of interaction associated with these materials concerns the electronic states and transitions expected in stacks of TMDC monolayers. We will present results of studies of the optical response of vertical heterostructures composed of two monolayers the same material (but with an adjustable twist angle) and bilayers of two different crystals. In the latter case, we have identified spectroscopic signatures for rapid charge separation associated with the staggered band structure.