Quadrupolar, dipolar and droplet phases of excitons in trilayer transition metal dichalcogenides

M. Zimmerman [1,*], **R. Rapaport**[1], **S. Gazit**[1,2]

[1]The Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem 9190401, Israel
[2]The Fritz Haber Research Center for Molecular Dynamics, The Hebrew University of Jerusalem, Jerusalem 9190401, Israel

Dipolar excitons in trilayer transition metal dichalcogenide (TMD) structures can dynamically flip their orientation due to hole tunneling between outer layers. This renders the dipole orientation a dynamical degree of freedom that can quantum fluctuate. In that regard, a pioneering work by Slobodkin et al. has predicted a vanishing dipole moment of the exciton in the limit of large hole tunneling rates, resulting in a quadrupolar excitonic state. The unique interplay between the single exciton character and the dipole orientation dependent interactions gives rise to a rich phase diagram, including a density-dependent transition from a quadrupolar crystal into a staggered dipolar lattice [1]. In the context of experiments, the quadrupolar nature of the excitons was recently measured by several groups in different TMD settings via measurements of a quadratic dependence of the exciton blueshift on an externally applied transverse electric field [2, 3, 4, 5, 6].

In this work, we employ numerical quantum Monte Carlo methods to study the trilayer system. Our model consists of point dipolar bosons and allows for a dynamic flip of the dipole moment. Focusing on experimentally relevant densities and hole tunneling rates, we find that excitons reside in the single particle quadrupolar state and condense into a superfluid below the Berezinskii–Kosterlitz–Thouless critical temperature. Notably, the quadrupolar superfluid persists across all densities up to the Mott transition, driven by the dominance of dipole moment fluctuations over dipolar interactions. By tuning system parameters, we uncover additional phases. Reducing the hole's tunneling rate leads to a novel low-density droplet state while increasing the mass stabilizes a high-density staggered square lattice. Our findings enlighten existing experimental results and might inspire future experiments in TMD excitons.

References

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*E-mail: michal.zimmerman@mail.huji.ac.il