Unconventional high-temperature excitonic insulators in two-dimensional topological materials

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Bound electron-hole pairs in semiconductors known as excitons can form a coherent state at low temperatures akin to a BCS condensate. The resulting phase is known as the excitonic insulator and has superfluid properties. We have theoretically studied [1] the excitonic insulator in a pair of recently proposed [2] two-dimensional candidate materials with nontrivial band topology (AsO and the MXene $Mo_2TiC_2O_2$). The nonzero Chern numbers of the electronic bands result in Wannier orbitals which cannot be exponentially localized. This leads to anomalous interaction channels that violate the individual electron and hole number conservations. Their inclusion is crucial to determine the symmetry of the electron-hole pairing. By performing mean-field calculations at nonzero temperatures, we find that the order parameter in these systems is a chiral *d*-wave. I will discuss the nontrivial topology of this unconventional state and give an overview of its superfluid properties. In particular, we estimate BKT temperatures between 75 K and 100 K on realistic substrates, over an order of magnitude larger than in the number-conserving approximation where *s*-wave pairing is favored. Furthermore, we propose an experimental setup which could distinguish this excitonic insulator phase from the underlying noninteracting topological insulator by leveraging their topological properties. Our results highlight the interplay between topology at the single-particle level and long-range interactions, motivating further research in systems where both phenomena coexist.

References

[1] L. Maisel Licerán, H. T. C. Stoof, arXiv preprint arXiv:2501.18694
[2] H. Yang, J. Zeng, Y. Shao, Y. Xu, X. Dai, X.-Z. Li, Physical Review B, 109.7 (2024), 075167

Figures

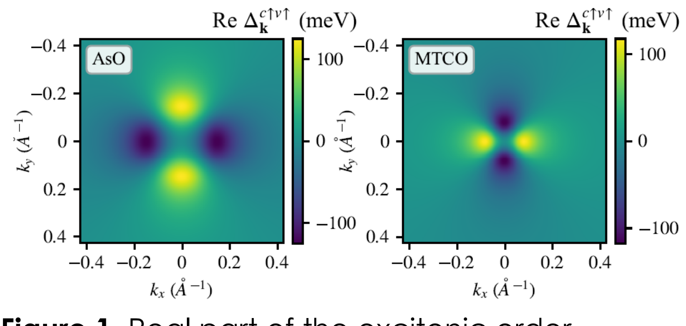

Figure 1. Real part of the excitonic order parameters in the proposed candidate materials in the shape of a chiral *d*-wave. This winding results in a topological excitonic insulator, where the quasiparticle bands have nonzero Chern numbers.

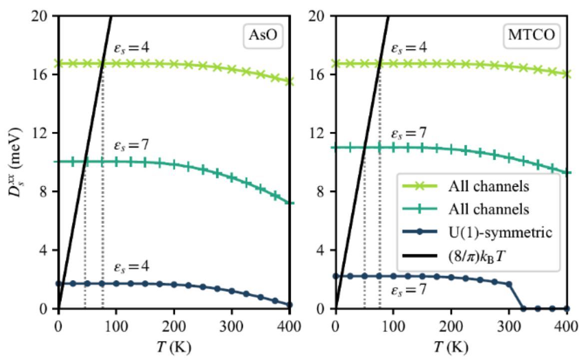

Figure 2. Superfluid density of the excitonic insulator in the presence of all anomalous interaction channels, and for the number-conserving case. The latter is much larger than the former and leads to higher critical temperatures (dotted lines), even on substrates with high dielectric constant ϵ_s.