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Competing orders in rhombohedral N-layer graphene

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We investigate the emergence of correlated electron phases in rhombohedral N-layer graphene due to two-valley Coulomb interactions within a low-energy $k \cdot p$ framework. Analytical expressions for Lindhard susceptibilities in intra- and intervalley channels are derived, and the critical temperatures for phase transitions are estimated using both the random phase approximation (RPA) and the parquet approximation (PA). Within RPA, only Stoner and intervalley coherent (IVC) phases are supported, while the PA reveals a richer phase structure including particle-particle (PP) channel instabilities. Magnetoelectric control of orbital magnetic order in crystalline rhombohedral hexalayer graphene (R6G) is achieved without introducing a moire superlattice. A hallmark of this magnetic order, which implies time-reversal symmetry breaking, is a finite Hall conductance at zero magnetic field. We observe a non-volatile and hysteretic anomalous Hall effect that can be electrically toggled by sweeping either the carrier density or the displacement field.
A model describing this behavior is proposed.

A. Herasymchuk, S.G. Sharapov, O.V. Yazyev, Y. Zhumagulov, Phys. Rev. B 113, 035132 (2026)

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