

Editorial: Closing Special Collection on 2D Materials

The isolation of graphene, a monolayer of carbon atoms arranged in a honeycomb lattice, in 2004 not only revealed relativistic Dirac electron physics but also ignited broad interest in intrinsic topological phenomena and ushered in the era of two-dimensional (2D) materials. Over the past two decades, this rapidly expanding field of 2D materials has profoundly reshaped the landscape of condensed-matter physics, materials science, nanoscience, optics, and related disciplines. In this spirit, this Editorial, which brings the *Physical Review X* (PRX) Special Collection on 2D Materials to a close, highlights the eight invited articles in the collection and warmly welcomes new submissions on 2D materials to PRX.

A defining strength of 2D materials is their extraordinary flexibility for engineering structural, electronic, magnetic, optical, and topological phenomena. By stacking, twisting, and electrostatically tuning layered 2D systems, researchers can tailor band structures, electronic and magnetic interactions, and lattice symmetries with a level of control that is difficult, and often impossible, to achieve in conventional three-dimensional bulk materials. The eight articles assembled in this collection exemplify the vitality and breadth of the field's most recent frontier advances, spanning correlated and topological moiré systems, topological photonics, complex magnetism, emerging 2D electron systems, and defect physics.

A recurring theme across several contributions of the PRX Special Collection is the role of moiré superlattices in realizing strongly correlated states. When layered materials are stacked with a small twist angle or lattice mismatch, the resulting periodic moiré potential can substantially modify the electronic structure, often producing narrow bands in which electron-electron interactions become dominant and thereby introduce correlated electron physics in the 2D limit. Semiconductor moiré superlattices based on transition-metal dichalcogenides (TMDs) provide particularly versatile platforms for studying such 2D correlated physics and, owing to strong spin-orbit coupling, for investigating topological physics as well. Optical probes of these systems can reveal how excitons and trions respond to these electronic correlations. The observation of confined trions and signatures of charge ordering in a TMD monolayer subject to a purely electrostatic moiré potential demonstrates how exciton spectroscopy can access interaction-driven states such as Mott-Wigner phases [1]. Moiré systems have also been shown to host topological electronic states with electrically tunable magnetism. In twisted MoTe_2 bilayers, current-induced manipulation of spin-valley polarization enables control of the helicity of light emission, illustrating how electronic topology, magnetism, and optical selection rules can become intertwined within a single atomically thin material [2].

Closely connected to these developments of TMD moiré systems is the exploration of flat-band physics in twisted graphene systems and rhombohedral graphene multilayers. Studies of superconducting proximity effects in twisted bilayer graphene Josephson junctions probe how superconducting correlations evolve as the system approaches the flat-band regime [3]. The observed deviations from conventional scaling relations between critical current and normal-state conductance point to the importance of strong interactions, multiband pairing processes, and quantum geometric effects. These studies illustrate how moiré materials allow us to open a new route to unravel long-standing questions concerning superconductivity and correlated electronic behavior.

Topological and correlated concepts developed in electronic materials are increasingly being extended to photonic and polaritonic systems. In strongly coupled light-matter systems, hybrid quasiparticles known as polaritons inherit properties from both photon and exciton components. By engineering photonic crystal band structures and leveraging exciton-enabled symmetry breaking, it becomes possible to realize polariton bands with nontrivial topology. One contribution shows that polariton Chern bands can be realized in 2D photonic crystals beyond

the conventional Dirac-cone framework, positioning us to explore large topological gaps and higher Chern numbers in photonic systems [4]. These results illustrate how ideas originally developed from electronic topological and correlated materials can be translated to optical platforms.

Magnetism in 2D systems provides another prominent venue for correlated physics and is itself a rapidly advancing field. Complex magnetic textures can emerge in materials with carefully engineered magnetic interactions, yet realizing and characterizing such textures in reduced dimensionality remains challenging. Examining the spin dynamics of a complex multi- Q magnetic order on a triangular lattice shows that the anisotropy of long-wavelength magnon velocities offers a robust diagnostic for distinguishing a symmetry-preserving triple- Q state from symmetry-breaking single- Q or double- Q configurations [5]. These results demonstrate how inelastic dynamical probes can complement elastic diffraction measurements in identifying magnetic structures, and they may prove broadly useful for investigating topological spin textures in 2D magnets.

The continuing expansion of the family of 2D electron systems remains an important theme. Ultrathin bismuth films grown by van der Waals (vdW) epitaxy on hexagonal boron nitride form high-quality 2D electron systems characterized by strong spin-orbit coupling and high carrier mobility. Transport measurements reveal Rashba-split surface states and signatures of symmetry breaking in the quantum limit, suggesting that such systems may provide a promising platform for exploring topological and interaction-driven phenomena in materials beyond graphene, TMDs, and 2D magnets [6].

Defects and localized quantum emitters represent another important direction in 2D materials research. Hexagonal boron nitride, widely used as a substrate and dielectric layer in vdW heterostructures, also hosts optically active defect centers that are promising candidates for quantum technologies. Identifying the microscopic origin of these defects has long been a challenge. By combining isotope substitution with control over the stacking polytype of the host crystal, recent work demonstrates a systematic approach for identifying point defects in layered materials. Applying this methodology to a well-known ultraviolet-emitting defect in hexagonal boron nitride establishes its microscopic origin as a carbon dimer embedded in the lattice [7]. More broadly, such studies illustrate how subtle structural variations in layered materials can be exploited to understand and engineer quantum emitters.

The Special Collection highlights several active directions in the field but does not encompass the full breadth of current 2D materials research. Important areas not represented include the active topics of exciton polaritons and strongly interacting excitonic fluids in monolayer semiconductors, the rapidly developing field of 2D ferroelectrics and multiferroics, and the growing studies of superconductivity and topology in layered materials beyond graphene- and TMD-based systems. Other vibrant directions include strain engineering and twistronics in complex heterostructures, nonlinear and ultrafast optical phenomena in atomically thin crystals, and the integration of 2D materials into quantum technologies and hybrid quantum systems.

All these developments underscore how 2D materials have become a powerful platform for exploring a wide range of physical phenomena. Continued advances in materials synthesis, heterostructure assembly, and experimental probes are expanding the range of accessible systems, while theoretical progress is providing new perspectives on topology, correlations, and quantum geometry. As these directions continue to converge, 2D materials are likely to remain a central arena for discovering and understanding new states of quantum matter, as well as for realizing novel electromagnetic responses for application potential.

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