Recent Advances in "Colloidal" Quantum Materials

Yi-Hsin Liu

National Taiwan Normal University, Taipei City, Taiwan

Our study explores Mn-doped 2D semiconductor nanosheets and 0D magic-sized nanoclusters, emphasizing the interplay between Zeeman splitting, spin-polarized quantum states, and magnetic phenomena. Combining advanced techniques such as magnetic circular dichroism (MCD), electron paramagnetic resonance (EPR), and density functional theory (DFT), the research demonstrates the potential of these materials in spintronic and quantum applications. Neutron scattering methods, particularly inelastic neutron scattering (INS) and small-angle neutron scattering (SANS), provide critical insights into the magnetic structure, spin dynamics, and exchange interactions.

1. **Enhanced Magnetic Moments and Quantum Spin Behaviors:** Mn-doped $(CdSe)_{13}$ nanoclusters exhibit Bohr magneton numbers exceeding 40 μB at 180 K, highlighting strong spin-spin interactions, spin fluctuations, and magnetic polaron formation. In $CdSe(en)_{0.5}$ and $ZnSe(en)_{0.5}$ monolayers, Mn doping induces robust spin-orbit coupling (SOC) effects and unique spin-polarized quantum confinement, enabling room-temperature exciton dynamics critical for spintronic applications.
2. **Magnetic Polaron Formation:** INS captures localized magnetic excitations associated with magnetic polarons. The strong spin-spin interactions observed in Mn-doped $(CdSe)_{13}$ nanoclusters, attributed to giant Bohr magnetons, exemplify the role of localized charge redistribution in enhancing magnetic properties.
3. **Spin-Orbit Coupling and Quantum Behavior: T**he interplay of SOC and exchange interactions is critical in stabilizing nontrivial spin textures, such as skyrmions. Neutron scattering validates theoretical models of these phenomena by revealing spin configurations and dynamic behaviors.
4. **Applications in Advanced Quantum Technologies:** The unique properties of Mn-doped 2D materials and nanoclusters pave the way for next-generation quantum devices, such as spintronic memory systems, magnetic sensors, giant magnetoresistance technologies, and quantum computing platforms.

Current research provides a foundational understanding of how Mn doping modulates electronic, optical, and magnetic properties in low-dimensional materials, offering critical insights into the design of functional quantum devices leveraging tunable spin and magnetic phenomena.

References:

[1] C. Li, S.-C. Hsu, J.-X. Lin, J.-Y. Chen, K.-C. Chuang, Y.-P. Chang, H.-S. Hsu, C.-H. Chen, T.-S. Lin, Y.-H. Liu, J. Am. Chem. Soc. **2020**, *142*, 20616–20623

[2] G.-L. Huang, K.-Y. Ting, N. Narayanam, D.-R. Wu, T.-E. Hsieh, K.-C. Tsai, D.-W. Yang, Q.-X. Tang, B.-K. Su, Y.-T. Kang, *Angew. Chem. Int. Ed.* **2024**, *63*, e202420257.