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Topological structures in ferroelectric nanoparticles

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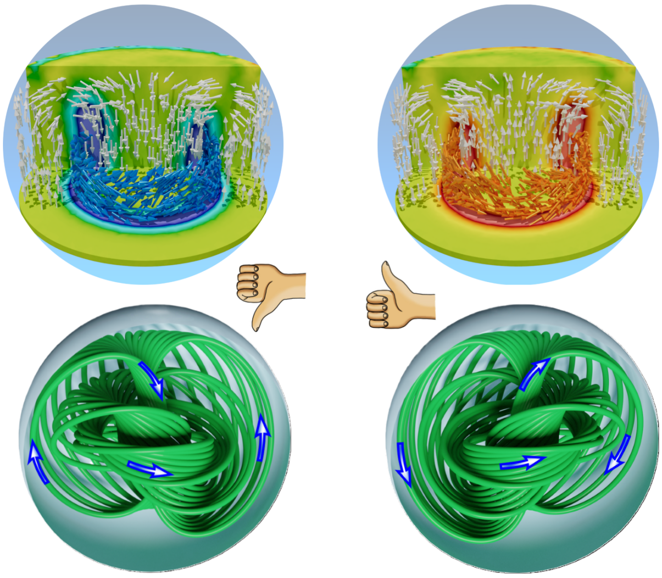

Non-uniform texturing of the vector order parameter in confined ferroics arises from the interplay between the exchange and dipole-dipole interactions, elastic strains, anisotropic energy, and confinement effects. Textures possessing the definite handedness (chirality), – Bloch domain walls, merons, skyrmions, and Hopfions, – attract particular interest due to their fundamental importance and numerous potential applications. In both magnetic [1,2] and ferroelectric [3,4] materials chiral structures may emerge spontaneously in order to reduce the stray fields, even in the absence of the chirality-generating local antisymmetric (Dzyaloshinskii-Moriya) exchange interactions.

The effect is especially pronounced in confined ferroelectrics due to the large electrostatic energy induced by the depolarization field of bound charges. To avoid their formation, a topological constraint of zero field divergence applies to the polarization field. The approach to study fundamental topological structures emerging in a divergenceless vector field was developed by Arnold [5] for topological hydrodynamics. When applied to nanostructured ferroelectrics, Arnold's theorem predicts the emergence of two types of elementary topological excitations: 2D (achiral) vortex states [6] and 3D (chiral) knotted structures – Hopfions [3], which provide the chirality in confined ferroelectric systems. Importantly, the topological origin of chirality enables ways to manipulate and switch it, resulting in new controllable functionalities.

[1] E. Berganza, et al., Sci. Rep. 12, 3426 (2022).
[2] F. Büttner, et al., Sci. Rep. 8, 1–12 (2018).
[3] I. Luk'yanchuk, et al., Nat. Commun. 11, 2433 (2020).
[4] Y. Tikhonov, et al., Sci. Rep. 10, 8657 (2020).
[5] V. I. Arnold and B. A. Khesin, Topological methods in hydrodynamics. Springer International Publishing (2021).
[6] S. Kondovych, et al., SciPost Phys. 14, 056 (2023).