Designing fractal defect structures in liquid crystals

Fractal nematic colloids
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Topological defects are discontinuities in solid or liquid materials. Such singular points, lines or surfaces often play a crucial role in determining the elastic, electric or optical properties of the underlying medium. Well-known examples range from vortex lines in quantum superfluids and grain boundaries in magnets to domain structures formed in the early universe. Nematic liquid crystals [1] consisting of rod-like or disk-shaped molecules exhibit a particularly interesting class of topological defects. These liquid crystal defects can be made directly visible under polarized light, giving rise to beautifully structured and colored patterns. The ability to control precisely the location and dynamics of nematic defects promises a range of novel technological applications, including highly-tunable photonic materials and metamaterials [2], as well as steering devices for microbial locomotion [3]. Recent experimental [4] and theoretical [5] advances revealed that suitably designed colloidal objects can be used to realize knotted and other complex defect structures in nematic liquid crystals. Building on these insights, Hashemi *et al.* demonstrate in their paper through experiments and simulations how a similar approach allows the creation of fractal defect structures spanning three orders of magnitude in size from the nano- to micrometer scale.

Fractals are self-similar patterns that can have non-integer Hausdorff dimension. In their work, Hashemi *et al.* focus on a particular type of fractal known as the Koch snowflake, obtained by starting from an equilateral triangle and successively replacing the middle third of each side segment by an equilateral triangular protusion. In the limit of infinitely many iterations, the fractal dimension of the Koch curve converges to $\ln 4/\ln 3 \approx 1.2618\ldots$. For their experiments, Hashemi *et al.* created colloidal structures realizing the first few iterations of a Koch snowflake by laser-writing in a photosensitive polymer. These fractal-like microstructures (diameter $20\,\mu$m, height $8\,\mu$m, side thickness $0.6\,\mu$m) were then embedded in a nematic liquid crystal confined between two co-planar top and bottom walls. Due to elastic distortion forces, the colloidal structures assume a levitating position between the walls, thus imposing a fractal boundary condition on the surrounding liquid crystal. Using polarization microscopy, Hashemi *et al.* found that the liquid crystal spontaneously develops defect loops that wrap around the sides of the colloidal structure following closely its fractal geometry. Their experimental results agree well with predictions from finite element simulations of a corresponding Landau-de Gennes free energy-minimization model. From a numerical perspective, finite element methods are well-suited for these types of problems as they allow a straightforward implementation of complex boundary conditions.

The work of Hashemi *et al.* provides a beautiful illustration for how suitably designed boundary geometries can be used to precisely control topological defect structures in anisotropic fluids. A practical question implied by their research is whether, and to what extent, similar control can be achieved with other methods including, for example, surface patterning or externally applied static or dynamic fields. Furthermore, one can imagine several interesting future extensions in the context of active matter. Recent experiments show that active nematics, such as ATP-driven microtubules [6], can develop complex non-equilibrium defect dynamics and it would be intriguing to explore if and how immersed colloidal objects could be used to steer active fluid flows. Another biophysically relevant question concerns the possibility of designing topological traps for bacteria and other swimming cells by combining the approach of Hashemi *et al.* with that of Ref. [3]. More generally, investigating the dynamics of passive and active nematics in simple and complex geometric settings remains an interesting and worthwhile challenge, not least since a recent study [7] revealed that topological defects in cell packings correlate with cell death in epithelial tissues.

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