Opinion

Active nematic flows can be confined using curved fluid boundaries

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INTRODUCTION

Actively driven, bundled microtubule networks powered by molecular motors have proven a helpful framework for studying the dynamics the dynamics of energy-driven defects, although controlling defect movements remains a difficult task. We offer a method for confining active nematic fluid utilizing wetting to bend an oil layer over circular pillars in this work. This geometry, in which submerged pillars collide with an oil-water interface, results in a two-tier continuous active layer in which the material is restricted above and surrounds the pillars. The circular shape influences active flows above the pillars, which display dynamics comparable to those seen for active material constrained by hard barriers, such as inside circular wells.

The thin oil layer beneath the active material is much thinner above the pillars than outside their border, resulting in a greater effective friction area. Active length scales and velocities are reduced within the pillar area, whereas defect concentrations rise compared to outside the pillar border. This novel method of confining active flows expands the possibilities for controlling and organizing topological flaws, as well as studying their behavior in active systems.

Active materials are often made up of energy-driven particles or components that take fuel from their surroundings to generate mechanical forces that cause motion. Collectively, these active components can cause emergent dynamics and out-of-equilibrium phase behavior. Active materials on the micron scale vary from dilute colloidal solutions to highly concentrated lyotropic systems with local organizing fluxes. Bacterial suspensions and systems constructed from cellular filaments are two notable recent examples. A particularly noteworthy example of an active phase is the active nematic state created by bundled microtubules with kinesin. This material shows active turbulence, which occurs when the nematic fluid creates self-driven chaotic mixing defined by the movement of positive and negative topological defects. Topological defect movements in active nematic are fundamentally aperiodic in an open system with no known boundary restrictions. However, if these self-driven active flows can be regulated to generate more predictable dynamics, a wide range of microfluidic applications may arise.

As different patterned geometries may be constructed to induce unique flow dynamics and defect movements, confining active nematic flows to microfluidic devices may provide an appealing technique for material organization.

Previously, patterned surfaces were used to arrange material in passive liquid crystal devices. They offer a highly effective approach for aligning and influencing material in the liquid crystal phase without the need of external fields or mechanical forces. Simple geometries can improve anisotropic effects inside the material or build arrays of topological flaws; therefore the benefits of this method are numerous. Honglawan., for example, employed patterned surfaces to create arrays of sematic focal conic flaws. Active materials based on rod-like subunits, like passive liquid crystals, tend to align parallel to constraining limits and surfaces. This phenomenon, known as planar alignment, may be demonstrated in a variety of biopolymer studies and is required for mathematical models that take into account a physical boundary.

New discoveries in active nematics, including recent work by our group, have focused on comparable management of mobile topological flaws. Hardoüin. limited bundled microtubules to rectangular wells, while Opathalage. investigated active flow dynamics in cylindrical wells. Within these geometries, the active material aligns parallel to the hard boundaries, creating more orderly flows and spatially arranging the flaws. When the active nematic is spatially constrained, the geometry occupied (circular, rectangular, etc.) can drastically modify the active dynamics, resulting in various defect circulations and braiding. When active particles or phases interact with boundaries and structures of various forms, a range of intriguing phenomena have been observed. Using a submerged surface structure that is not in direct contact with the active fluid, our research has proved that discontinuities in the depth of the underlying fluid substrate (oil layer) may also create confinement effects. We demonstrated that the viscosity of the underlying oil substrate is critical in nematic alignment and flow kinematics. The consequence is that if a material's momentum is not preserved between spatial

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areas, friction will encourage planar anchoring between high and low friction contacts. According to, friction caused by a submerged pattern causes activity gradients on the surface, resulting in boundary alignment by adjusting the oil thickness. This exciting study shows that active flow control is not restricted to microfluidic systems with physical barriers, but can also be accomplished with a soft boundary formed by effective frictional discontinuity induced by the oil sublayer. This research extends the issue of soft confinement effects by giving proof of concept experiments that demonstrate how curvature in the active layer may cause localised confinement effects and hence govern active flows. In the examples shown, a circular pillar is used to produce a ring of local curvature that governs active nematic dynamics in the same way as cylindrical wells do. We show a range of phenomena caused by the confinement effect that are compatible with previous confinement approaches and measure flow velocities and pressures. Controlling active nematic flows using curvature is preferable to hard-well-based approaches because the active layer continuity is preserved and device-filling is simple. This innovative methodology adds a new to-
-ol to the growing toolbox for controlling active nematic fluxes. In this research, we show how surface-induced curvature in an active nematic layer may be used to contain topological flaws. We employed circular pillars that slightly impinged on the active layer from below to create a ring of interfacial curvature sufficient to restrict mobile topological defects to the pillar tops to achieve the curvature confinement effect. The continuous active layer is suspended in a thin oil layer above the pillars using this approach. Defect movements similar with previous confinement strategies, such as slower kinematics and larger defect density reported for thin underlying oil layers, are observed. Our pillar technique introduces local curvature, providing a novel tool for directing defect flows and investigating defect dynamics on curved landscapes. This technology may be used to create defect arrays and investigate defect-defect interactions in obstructed settings. It will also be intriguing to explore asymmetric pillar designs to increase the system's complexity. This proof-of-concept technique adds to the growing set of instruments for controlling active nematics and may open up new avenues for basic research.