Zooming defects in bio-nematics – A theoretical analysis

Defect Annihilation and proliferation in active nematics, Giomi, L., Bowick, M. J., Ma, X., & Marchetti, M. C., Phys. Rev. Let.t **110**, 228101 (2013).

Recommended with a commentary by Aparna Baskaran, Brandeis University

Context and Overview: Liquid crystals are prototypical complex fluids that have been of central interest in soft condensed matter physics. They have served as the launch pad for symmetry based understanding of structure and dynamics in anisotropic materials [1]. It has been realized in the past couple of decades that a number of biological systems ranging from bird flocks to confluent cells sheets can be viewed as living liquid crystals in that they are made of anisotropic microscopic entities that collectively form macroscopic anisotropic states [2]. But in stark contrast to materials, these systems are inherently maintained out of equilibrium due to the individual entities in the system consuming energy and generating stresses. This class of systems has been termed active liquid crystals.

Fig 1: Left – Microscopic picture of nematogens, head-tail symmetric rod like objects that align when densely packed (image courtesy wikipedia). Right – Macroscopic view of a nematic liquid crystal film under cross polarizers showing defect pairs (image courtesy NSF Science360)

Once the theoretical paradigm of active liquid crystals had been established, the well developed machinery of soft condensed matter physics and symmetry based hydrodynamic theories has been brought to bear on these complex biological systems [3] and has enabled us to understand bulk states and fluctuations seen in diverse systems ranging from bacterial colonies to the cytoskeleton of the cell. The work that is featured here [4] considers a specific problem : Suppose we had an active nematic system that was a suspension of active particles in a thin film of fluid. Can we understand the dynamics of topological defects in this system using this hydrodynamic approach? This question is of topical relevance due to the advent of quantitative experiments that realize precisely such an active nematic [5].

Results : It is well known that in a nematic material, energetics dictate that defects of opposite topological charge experience a logarithmic attractive interaction that causes them to annihilate and restore the homogeneous order in the system [6,7]. This is the entire dynamical picture in a molecular nematic. When the nematic is made of a particulate phase of nematogens suspended in an isotropic continuous fluid, the fluctuations in the order in the particulate phase influence the suspending fluid and induce flow. This has been termed backflow, and it preferentially propels the defect of positive topological charge, yielding an asymmetry in the dynamics of +1/2 and -1/2 disclination pairs (see for example reference 24 in the featured work). In the case of active nematogens, there is additional stress on the solvent due to the activity of the individual entities. These active stresses can be contractile, as in actomyosin systems, or extensile, as in the microtubule bundle suspension studied by Sanchez et al [5]. The featured work demonstrates that the active backflow yields an additional contribution to the velocity of +1/2 defect that depends on the sign of the activity. In contractile systems the comet-like +1/2 disclination is actively propelled to move towards its tail, while in extensile systems the active backflow yields a net speed towards the head of the defect. As a result, for certain relative orientations of a defect-antidefect pair, activity can yield an effective repulsion of opposite sign defects, as demonstrated in Fig. 2 of Giomi *et al* for an extensile system, and as seen in experiments. Additionally, even when a pair annihilates as it does in equilibrium, the dynamics does not stop there, as activity continuously generates new defect pairs and the system settles in to a defective steady state with chaotic dynamical behavior.

Significance and outlook : The authors of the featured work use the primary result described above to reformulate the defect dynamics in an active nematic by treating the defects themselves as self-propelled particles with prescribed equilibrium interactions. This reformulation is significant in the following sense. There has been extensive discussion of "low Reynolds number turbulence" in active liquid crystal systems in the recent literature (for example references 12 and 13 in this paper). By thinking of the defects as self-propelled particles, we could potentially understand the turbulent emergent flows in active fluids in a systematic yet tractable manner, as an emergent consequence of the dynamics of interacting defects. This might prove to be the most useful theoretical paradigm to handle an otherwise intractably complicated physical phenomenon.

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