Three-Dimensional Active Liquid Crystals: Defects and Topology

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Active matter is a class of materials in which the individual constituents continually consume energy to generate work or motion, maintaining the system in dynamic, self-organised, non-equilibrium states [1]. Examples derive readily from the study of living systems, ranging from intracellular organisation to swarming bacteria, but they can equally be realised synthetically in self-propelled colloids or microtubule mixtures, or in the collective dynamics of skyrmions and other solitons in liquid crystals. These systems are providing fundamental insight into nonequilibrium physics and a framework for the interface between physics and biology. The formalism of active liquid crystals [2] has emphasised the key role of topology in active matter, showing the significance of active topological defects to 'turbulence' in bacterial suspensions, cell populations, cultures and tissues, as well as synthetic active nematics. The major focus to date has been on two-dimensional active systems, in which the topological defects spontaneously self-propel, however, recently experimental results have begun to emerge also in three dimensions.

In three dimensions, the defects arise as lines and closed loops, rather than simple points, and exhibit a complex interplay between geometric structure and topology-affected dynamics [3]. The materials can adopt a natural or spontaneous twisting to produce a preferred chirality, and they support a variety of fascinating localised solitons. In this project we will develop the theoretical understanding of three-dimensional active liquid crystals, with focus on their topological defects, soliton structures and geometric characteristics. We will combine analytical descriptions of defect loops and the active flows they generate with numerical solutions of the full non-linear hydrodynamic equations to establish their dynamic properties, instabilities and phase behaviour. These insights will allow us to extend the existing connections between active liquid crystals and living systems to bulk three-dimensional cell structures, tissues and their morphology. A further direction will be to determine how three-dimensional active materials may be controlled geometrically and topologically – for instance by boundaries, inclusions, or applied fields – and subsequently designed to create artificial active metamaterials.

References

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