ACTIVE NEMATICS

Turbulent beginnings

An inspired experimental approach sheds light on the formation of active turbulence in a system of microtubules and molecular motors. The emergent scaling behaviour takes us a step closer to understanding how activity begets turbulence.

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A comparison between passive and active liquid crystals reveals dramatic differences. A uniformly aligned passive nematic is in its equilibrium state and will remain aligned unless acted upon by an external force. In contrast, a uniformly aligned active nematic is intrinsically unstable; its director spontaneously bends and the fluid begins to flow, driven solely by the consumption of chemical energy. Writing in *Nature Physics*, Berta Martínez-Prat and co-workers have captured the initial instability in a two-dimensional nematic consisting of bundles of microtubules and their associated kinesin motors deposited on an oil–water interface[1].

The experimental challenge was aligning the active nematic at the beginning of the experiment. In previous studies of this system, the instability, which occurs rapidly, would happen out of sight while the experimenters were loading the samples onto the microscope. To overcome this, the team inserted a straw into the centre of the sample at the oil–water interface, thereby drawing in material and creating radial flows that aligned the microtubules.

The initial state immediately after withdrawing the straw resembled a bicycle wheel with the spokes radiating outward from the hub (Fig. 1a). What followed next was dramatic. First, the aligned microtubule fibres began to undulate as they extended and periodically buckled, leading to a collective instability that resulted in alternating rings of ±½ topological defects in the liquid crystal (Fig. 1b). The +½ defects acted as active quasiparticles that generated flow by propelling themselves forward and reoriented the microtubules into alternating bands of circumferentially aligned regions (Fig. 1c). Next, these aligned bands themselves became unstable and buckled, re-establishing the radial alignment (Fig. 1d). After another cycle or two of this striking sequential folding, the active nematic became fully turbulent (Fig. 1e).

An outstanding question in active-matter research is how to relate the microscopic parameters of the system, such as the ATP, motor and microtubule concentrations, with the continuum values of the theory, such as elasticity of the nematic, or its activity. Martínez-Prat and colleagues measured the growth rate and the wavevector of the instability as a function of these microscopic parameters. One of the most significant findings was that the measured growth rate scaled quadratically with the wavevector of the initial instability, collapsing onto a single master curve, independent of which physical parameter was varied. This implied that the growth rate in turn scaled with activity, as did the square of the wavevector, results that have been predicted by theory and observed in other systems, such as bacteria[2].

As the field of active matter matures, there is an increasing need to quantitatively compare theory and experiment. The testing of scaling laws, as done by Martínez-Prat and colleagues, is a first step. But even this step is challenging. In their data analysis, the team assumed the activity was proportional to the logarithm of the concentration of ATP. A recent paper suggests another expression for the activity based on the fact that the speed of single kinesin motors follows Michaelis–Menten kinetics[3]. Underlying these differences is a lack of understanding of how the microtubules are organized within bundles. Research to elucidate how the microscopic motions of kinesin motors moving within bundles of microtubules translates into active stress is underway, but the physical picture is far from clear[4].

Scaling laws require measurements spanning multiple orders of magnitude

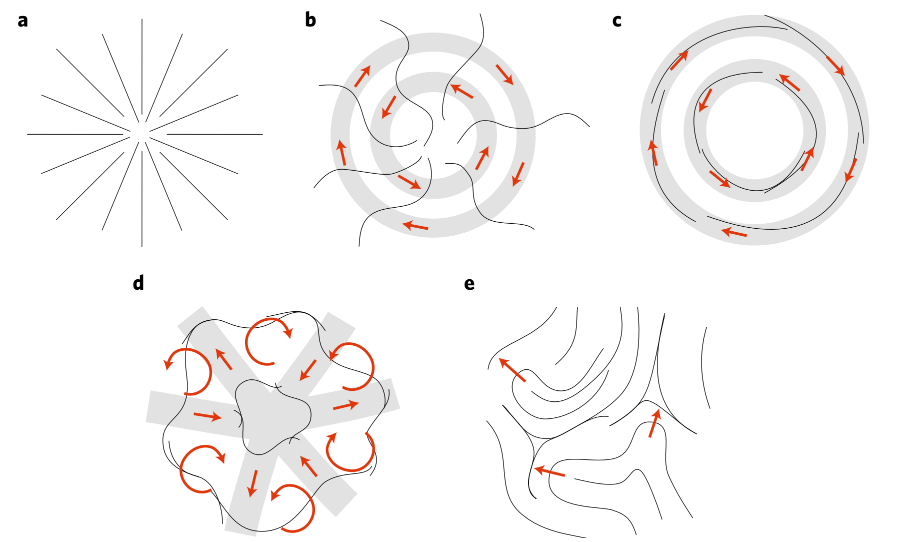

Fig. 1 | Transition to turbulence. Microtubules mapping the nematic director in black, defects in grey with flow direction marked in red. **a**, In the experiment by Martínez-Prat and colleagues, microtubules initially radiated outward. **b**, A collective instability then produced alternating rings of ±½ topological defects. **c**, The defects reoriented the microtubules into alternating bands of circumferentially aligned regions. **d**, A second instability generated radially aligned bands of defects and reoriented the microtubules. **e**, Finally, the active nematic became fully turbulent.

to be reliable, so beyond the issue of whether or not the relationship of activity to ATP concentration is correct, is the problem that the data for the scaling law cover less than an order of magnitude in ATP concentration. To make progress beyond scaling laws, researchers are now quantitatively comparing detailed dynamics between numerical models and experiment — revealing ways in which theory and experiment agree, and more importantly for pushing the field forward, disagree[5–7]. ❐

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