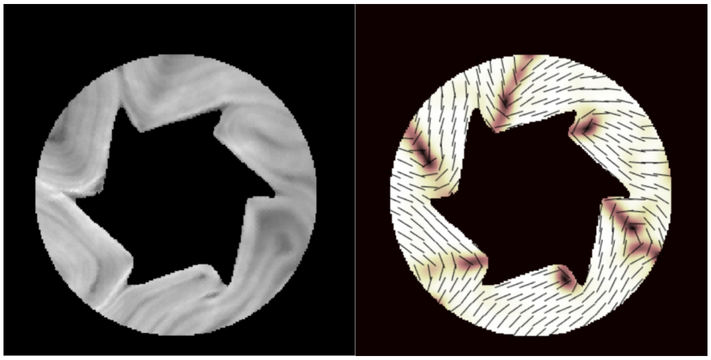
Active Matter Turns Pinwheels

The chaotic motion in a fluid of microscopic, actively moving rods can be harnessed to drive the rotation of a small propeller-like object.

By **Michael Schirber**

The chaotic motion of a collection of actively moving molecular rods can be harnessed to rotate millimeter-sized propellers and pinwheels, according to new experiments [**1**]. The rod motion was driven by chemically powered molecular motors that cause neighboring rods to connect and pull past one another. The ability to convert the energy of these microscopic machines into large-scale motion might eventually be used to drive small pumps that work without external power.

Active matter refers to a collection of objects that can move on their own via some energy-consuming process. It is often characterized by its ability to create order from disorder. For example, certain bacteria in isolation swim in no particular direction, but researchers have shown that these bacteria can collectively turn a microscopic gear by preferentially bumping into one side of the gear notches [**2**].

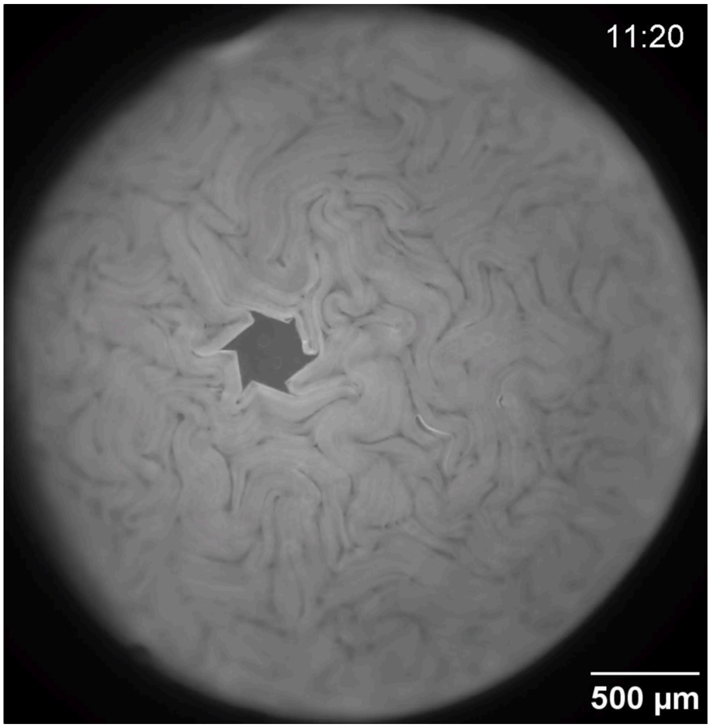


Activating rotation. A pinwheel-shaped object can be driven to rotate in a fluid composed of microscopic, actively moving rods. The left image shows the chaotic motion in the fluid caused by rod movements. The right image shows the estimated orientations of the rods. (See videos below.)
Credit: S. Ray *et al.* [1]

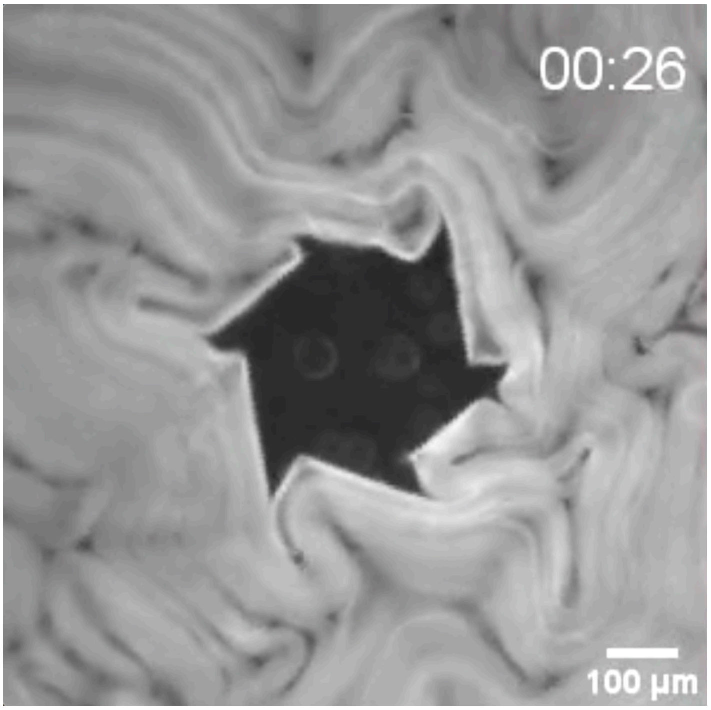
Other types of active matter exhibit collective motion through an alignment of rod-like elements. This so-called active nematic behavior is common in certain types of biological tissues, such as layers of elongated epithelial cells (see **Synopsis: Extending and Contracting Cells**). The active elements normally align with each other, but their individual motions can lead to regions of misalignment called defects. These regions form and move around in an unpredictable fashion. “One of the intriguing aspects [of active nematics] is that we can harness this internally generated chaos to create some kind of coherent motion,” says Zvonimir Dogic from the University of California, Santa Barbara.

Dogic and his colleagues performed an experiment with an active nematic material that combines a molecular motor protein called kinesin with rod-shaped biopolymers called microtubules. Inside cells, microtubules act as the highways along which kinesin molecules pull cellular cargo. In a concentrated soup of microtubules, a kinesin molecule can grab onto two neighboring microtubules and cause one to slide past the other. This behavior leads to two types of defects in the alignment patterns: comet-shaped “positive” defects and triangular “negative” ones (where the sign is based on the microtubules’ orientations around the defect).

The researchers studied the motions of these two defect types in a cylindrical tank where the active nematic was confined to the two dimensions of an oil–water interface. In the same tank, the team placed several-hundred-micrometer-wide floating objects having a variety of shapes—including circle, star, and pinwheel. The active nematic jostled the symmetric objects like the circle and the star but without inducing a net rotation. By contrast, the active nematic caused the pinwheel shapes to turn



The pinwheel-shaped object rotates clockwise (video sped up by 99×).
Credit: S. Ray *et al.* [**1**]



A close-up view of a pinwheel shows comet-shaped defects forming near the tips of the pinwheel blades. These defects approach the blades and then scatter outward, giving the pinwheel a rotational push in the process (video sped up by 20× and processed to remove the pinwheel rotation).
Credit: S. Ray *et al.* [**1**]

at a rate of around 0.2 revolutions per minute.

To explain these observations, the team tracked the defect motion in the tank, revealing an unexpected pattern of behavior around the pinwheel: positive defects routinely formed just behind the pinwheel blades. Each newly formed defect followed a similar trajectory of brushing over its associated blade and then shooting outward—a process that induced a new defect to form behind the blade. This cyclical pattern produced a net rotational force (torque) on the pinwheel. The average speed of the blades at their tips was about 3 μm/s, which was about half the average speed of the defects. Dogic says that this speed ratio is in the same general range as that of wind turbines, whose tips can move at 7 times the average wind speed (even though the geometry is different).

However, the rotational energy generated was small when compared with the amount of chemical energy that the kinesin molecules burn. “There’s a lot of energy that’s lost, and it’s not really clear where it’s lost,” Dogic says. Still, he foresees potential applications in microfluidics, as an active nematic could generate a net flow in a channel having walls covered by blade-like protrusions. The advantage here would be that the pumping would be self-sufficient—no outside power would need to be supplied, Dogic says.

“This research represents a beautiful union of fundamental geometry and topology that brings to life the ability to harness anisotropic active materials to power devices,” says Kathleen Stebe, a complex-fluids researcher from the University of Pennsylvania. “Active matter is becoming a mature field,” says soft matter specialist Seth Fraden from Brandeis University in Massachusetts. Theorists have modeled similar experiments, but there have been few experimental tests, he says. “The challenge for theory posed by this work is to reproduce the phenomena described here and then predict shapes of gears that extract maximal work from turbulent active fluids."

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REFERENCES

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