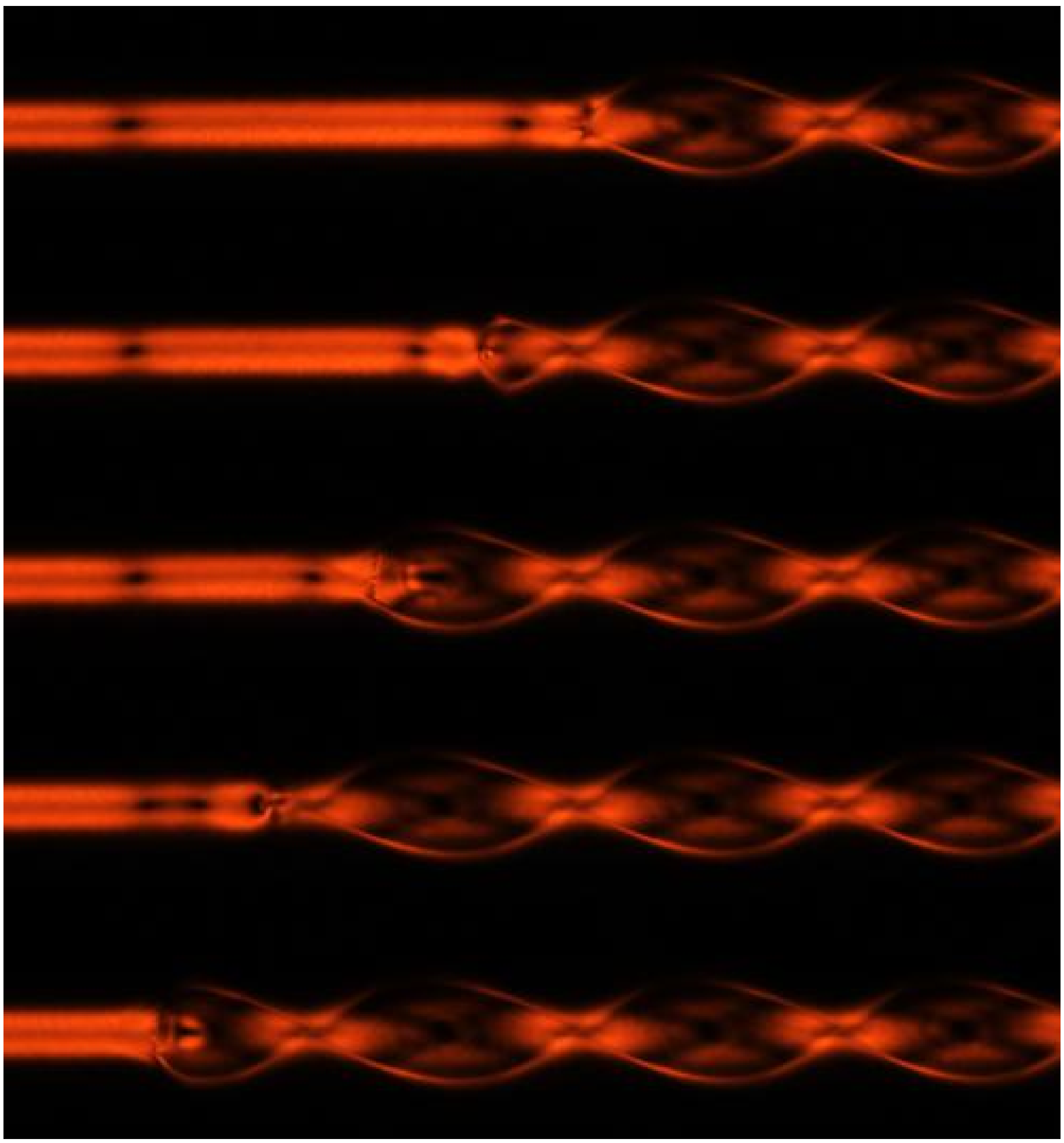
Research team discovers new liquid crystal configurations

April 1 2015, by Evan Lerner



Oil-based liquid crystals are ubiquitous; a deep understanding of their properties is behind the displays found in most computer monitors, televisions and smartphones. Water-based liquid crystals are less well understood, though their biocompatibility makes them a potential candidate for a variety of biological and medical applications.

New research from physicists at the University of Pennsylvania and Swarthmore College have advanced the field's understanding of this class of materials, demonstrating never-before-seen configurations by confining a water-based liquid crystal in a cylinder.

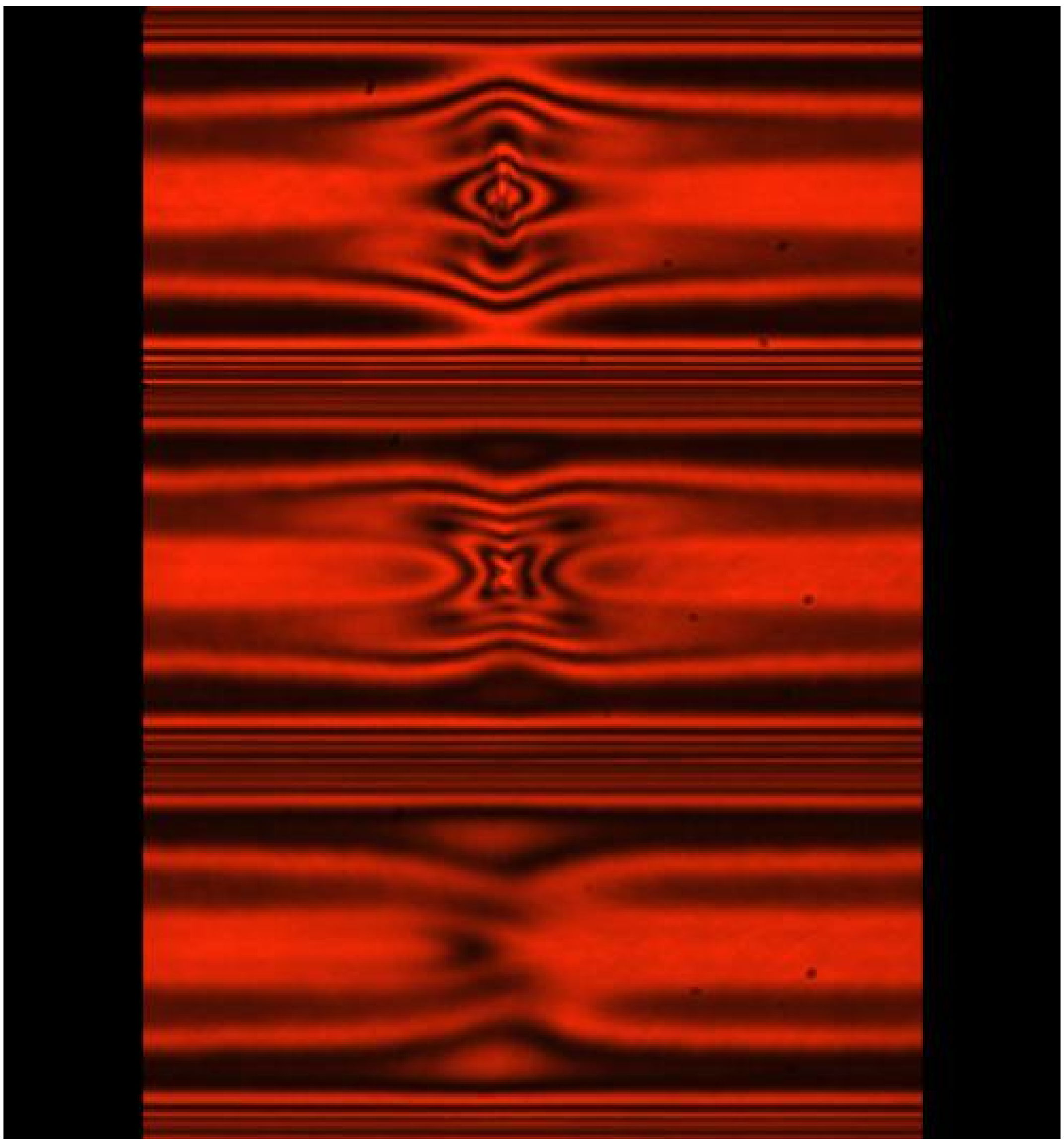
These liquid crystals are "achiral," meaning they don't have an intrinsic left- or right-handedness, but when placed in a cylinder they self-assemble into helical structures that have either left- or right-handed twists. Furthermore, when two structures with different handedness meet in the cylinder, a new type of defect interrupts the regular liquid crystal pattern.

On the microscopic level, the rod-like molecular structures that make up the water-based liquid crystals twist more easily than oil-based liquid crystals. This unusual elastic property is the key feature that makes the chiral helices possible. It differs from more common ways that helical structures are made to form, namely, by adding or using molecules that are themselves chiral.

The research was led by postdoctoral fellow Joonwoo Jeong and graduate students Zoey Davidson and Louis Kang, working closely with professors Arjun Yodh and Tom Lubensky at Penn and Peter Collings, a professor in the Department of Physics and Astronomy at Swarthmore.

Their study was published in the *Proceedings of the National Academy of Sciences*.

"Ultimately, our hope is that we can bring liquid crystal technology closer to biology," Yodh said. "To do that we need to better understand the kinds of structures water-based liquid crystals can make. Liquid crystals are a venerable field, and some of the chiral structures we observed are new kinds of configurations and defects that have never been seen over its long history."



The type of liquid crystals the researchers investigated in this study are so-called lyotropic chromonic liquid crystals, or LCLCs. The LCLCs used here were organic salts commonly known as "Sunset Yellow" or "Yellow 6," a widely used food dye found in orange soda, cheese-flavored snacks and many other products. When placed in water, individual molecules of the dye stack up like poker chips, forming microscopic rods that then assemble into more complex phases with long-range orientational order.

In an earlier study, the research team demonstrated the behavior of LCLCs when they were confined in spherical drops. In that case, the rods want to align with each other as well as with the walls of the sphere, but they have an increasingly difficult time doing so as they approach the poles.

"Liquid crystals have three modes of elastic deformations: splay, bend and twist," Jeong said. "With these liquid crystals, the resistance to twisting is very low. Splaying costs a lot of energy when the rods reach the defect, which is like the cowlick formed by the hair on your scalp, at the bottom or the top of the sphere, and so they relieve that stress by twisting relative to each other.

"In the cylinder, however, there is no equivalent of the cowlick-defect at the poles of the sphere. It essentially stretches out infinitely. We asked what happens when there aren't any boundaries in one direction and when the rods must lie perpendicular to the cylinder's inner surfaces?"

When placed in a hollow glass tube, oil-based liquid crystals with similar perpendicular orientation at the surface form a configuration known as "escaped radial" because the orientational order seems to be "escaping" in a series of concentric funnels pointing in one direction or another.

The researchers tried the same kind of experiments with water-based liquid crystals by coating the inside of a tube with a polymer-based substance and then filling it with water and LCLCs. The LCLCs did stick to the edges in the same perpendicular way. But, because their resistance to twisting is so low, the escape radial funnels they made had a distinct rotation to them, like the vortex of a tornado.

"To describe the system before, we just needed to know which way the crystals were escaping, say east or west," Collings said. "Now, we have to know east or west plus which way it's rotating, left or right. It's a much richer system."

After the chiral helices formed, the experimenters heated the system, sending the individual molecular rods into random alignment. They then let the sample cool into the aligned state, permitting formation of the most energetically favorable alignments. However, because the starting conditions for this process were random, different parts of the sample made either left- or right-twisting helices, and when regions with one handedness and escape direction encountered regions with different handedness or escape direction, then a new class of defects were found.

"We're adding new members to the zoo of liquid crystal defects," said Lubensky.

Surprisingly, defects never form where the escape directions of the neighboring domains differed but their handedness is the same.

"And if you wait even longer," Yodh said, "the configurations on the wall change, too, so that it becomes favorable to form a double-helix. We think this is due to reorientation of the liquid crystals on the wall, but we need to study it more."

Future experiments could look at whether it is possible to force these helices to form with a particular handedness or direction, which could be an important part in developing applications for them.

More information: "Chiral structures from achiral liquid crystals in cylindrical capillaries." *PNAS* 2015 ; published ahead of print March 30, 2015, DOI: 10.1073/pnas.1423220112

"Chiral symmetry breaking and surface faceting in chromonic liquid crystal droplets with giant elastic anisotropy." *PNAS* 2014 111 (5) 1742-1747; published ahead of print January 21, 2014, DOI: 10.1073/pnas.1315121111

Provided by University of Pennsylvania