Using achiral hard banana-shaped particles to assemble skyrmions and blue phases

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A research team has discovered that achiral hard banana-shaped particles can spontaneously form exotic structures like skyrmions and blue phase III phases. Their findings provide valuable insights into stabilizing skyrmion lattices and blue phases. They envision applying these liquid crystal skyrmions in memory and information processing devices. Credit: Marjolein Dijkstra/WPI-SKCM^2

A research team has discovered that achiral hard banana-shaped particles can spontaneously form exotic structures like skyrmions and blue phase III phases. Skyrmions are tiny vortex-like structures found in various condensed-matter systems, such as helical ferromagnets and liquid crystals. Blue phase III is an amorphous phase of liquid crystals that possesses strong optical activity. Achiral particles are particles that can be superimposed on their mirror image. The team's findings have potential applications in photonics and memory devices.

Their work was published in *Nature Communications* on August 8, 2024.

Skyrmions typically arise from chiral interactions, that is, a molecular interaction that occurs between molecules that both possess chirality. Molecules with chirality cannot be superimposed on their mirror images. British physicist Tony Skyrme introduced skyrmions in 1961.

Although the skyrmion model was originally developed for nuclear physics, it is also useful in explaining similar complex structures observed in condensed-matter systems. For example, in helical ferromagnets, skyrmions adopt a chiral spin structure with a swirling configuration.

These structures are topologically protected, meaning their topological properties protect them from changes. An energy barrier has to be overcome to remove the vortex-like structure. Because of these qualities, these systems have potential applications for information storage and processing.

Researchers attribute the emergence of skyrmions in such systems to the absence of inversion symmetry (or chirality) and the presence of interactions that arise because of spin orbit coupling. In recent years, there has been significant interest in skyrmions that originate in another class of materials governed by chiral interactions. These are highly chiral liquid crystals.

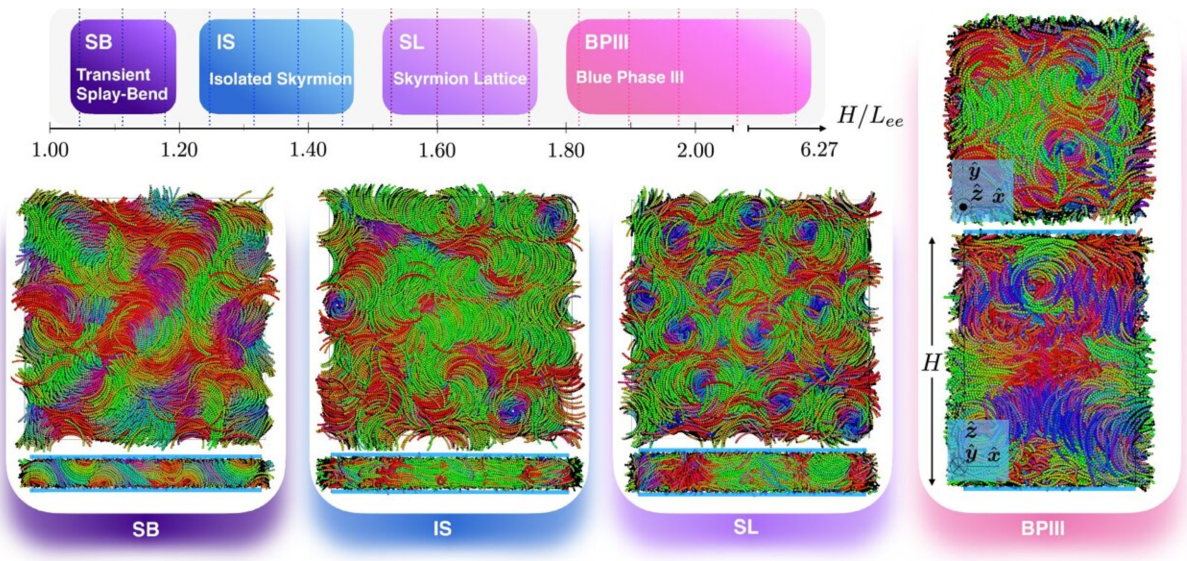
The team used extensive particle-based simulations to demonstrate that achiral hard banana-shaped particles, governed solely by excluded-volume interactions, spontaneously stabilize skyrmion structures.

"Under thin confinement, we observed the formation of quasi-2D layers of isolated skyrmions or dense skyrmion lattices. These structures, comprising a racemic mixture of left- and right-handed skyrmions, show resilience against thermal fluctuations while remaining responsive to external fields, offering intriguing possibilities for manipulation," said Marjolein Dijkstra, from Utrecht University and Hiroshima University's International Institute for Sustainability with Knotted Chiral Meta Matter (WPI-SKCM^2).

The team also found that the size of these skyrmions can be adjusted by the dimensions and curvature of the banana-shaped particles. The ability to control the skyrmion size could hold potential usefulness in the production of high-performance displays and the development of electro-optical, optical, and photonic devices.

Without the geometric frustration that results from confinement, the team noted that a blue phase III may emerge. These are characterized by a 3D network of chiral skyrmion filaments. The team also demonstrated that the skyrmions can be effectively created and annihilated by external electric fields. This shows the structures' robustness and also underscores their re-configurable and adaptive nature.

The team's observations of 3D blue phase III and 2D skyrmion phases are consistent with earlier theoretical predictions. These earlier predictions showed that the coupling between polar order and spontaneous bend deformations could lead to intricate higher-dimensional modulated structures beyond the one-dimensional spatially modulated twist-bend and splay-bend nematic phases.



Phase sequence of banana-like particles confined in thin layers. Credit: *Nature Communications* (2024). DOI: 10.1038/s41467-024-50935-4

The team's findings provide valuable insights into stabilizing skyrmion lattices and blue phases. They showcase non-Gaussian fluid-like dynamics in systems of achiral hard particles. Their findings also highlight the remarkable capacity of these complex fluids in designing advanced functional materials with diverse applications in photonics and memory devices.

Looking ahead, the team hopes to actually use these liquid crystal skyrmions in memory and information processing devices. Their findings highlight that these exotic structures, including skyrmions and the blue phase III phase, can be robustly realized in experimental systems composed of achiral bent molecules or colloids, broadening the potential for discovering new phases in diverse materials.

"We hope that our findings will inspire experimental investigations of bend-stabilized 3D blue phase III and 2D skyrmion phases in both thermotropic and lyotropic liquid crystals," said Dijkstra.

The research team includes Rodolfo Subert and Gerardo Campos-Villalobos from Utrecht University, The Netherlands, and Marjolein Dijkstra from Utrecht University and Hiroshima University, Japan.

More information: Rodolfo Subert et al, Achiral hard bananas assemble double-twist skyrmions and blue phases, *Nature Communications* (2024). DOI: 10.1038/s41467-024-50935-4

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