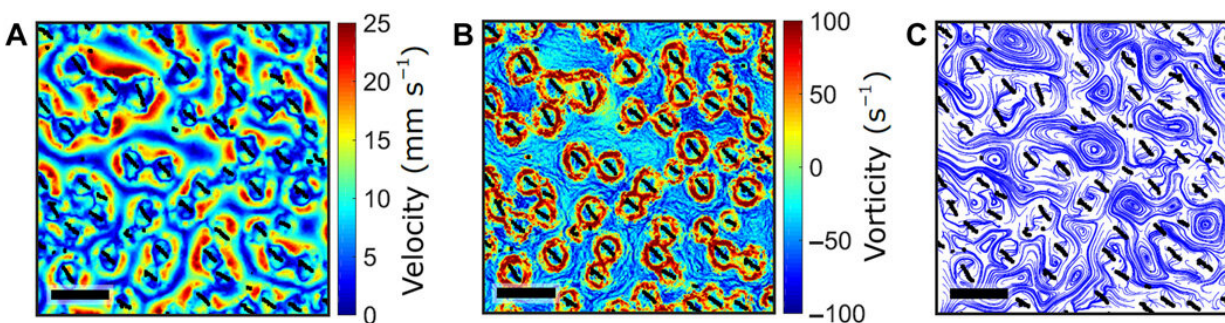


Reconfigurable structure and tunable transport in synchronized active spinner materials

March 27 2020, by Thamarasee Jeewandara



Simulating velocity, streamlines, and vorticity flow fields induced by synchronous spinners at a surface of water, as obtained in experiments. Credit: Science Advances, doi: 10.1126/sciadv.aaz8535

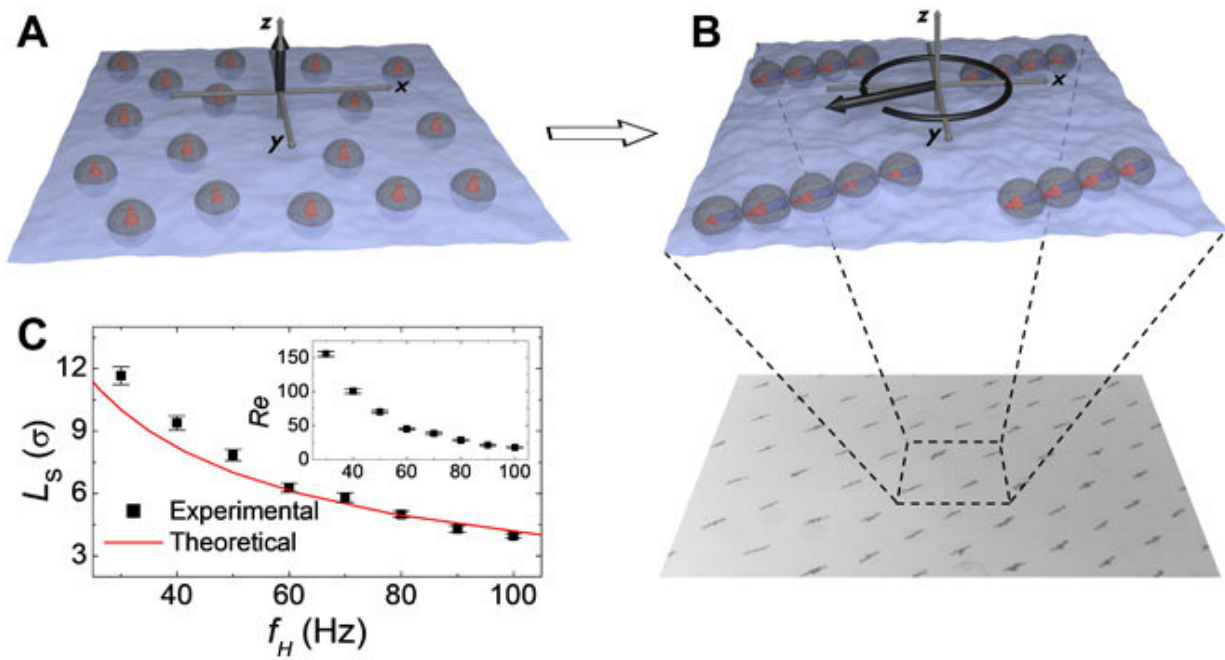
Actuated colloids are [excellent model systems](#) to investigate emerging out-of-equilibrium structures, complex collective dynamics and design rules for [next-generation materials](#). In a new report, Koohe Han and a research team suspended ferromagnetic microparticles at an air-water interface and energized them with an external rotating magnetic field to form dynamic ensembles of synchronized spinners. Each spinner generated strong hydrodynamic flows with collective interactions between multiple spinners to promote dynamic lattice formation. Using experiments and simulations they revealed structural transitions from

liquid to near crystalline states, demonstrating the reconfigurable nature of dynamic spinner lattices. The materials showed self-healing behavior and transported embedded inert cargo particles, tuned by the parameters of external excitation. The findings are now published on *Science Advances*, and provide insight to the behavior of active spinner materials with reconfigurable structural order and tunable functionalities.

Out-of-equilibrium particles can assign design rules for next-generation reconfigurable materials due to their [potential to self-organize](#). Scientists can [control the excitation field](#) parameters that are based on an external energy influx from an electric or magnetic field to change the dynamic and collective response of actuated particles in a regulated process . These field-driven active systems are promising candidates for applications in water purification and targeted drug delivery by [tuning their transport properties](#) on demand. Recent research has focused on self-propelled particles ranging from dynamic chaining and clustering to [flocking and active turbulence](#). Exploring dynamic self-assembly of colloidal particles can provide a robust technique to generate large ensembles of [microscopic spinners](#). These spinners are not easy building blocks for [dynamic assembly](#) as they rotate in random directions and disintegrate.

To gain better control and tunability of the active spinner material, the team developed a system of synchronously co-rotating self-assembled spinners that are stable and efficiently coupled through self-induced hydrodynamic flows. In this work, Han et al. reported the dynamic formation of swarms of synchronized and self-assembled spinners from [ferromagnetic nickel](#) (Ni) particles suspended at an air-water interface and energized with an in-plane rotating magnetic field. The self-assembled spinners generated strong hydrodynamic flows to cause a set of collective dynamic phases. Han et al. combined experiments and simulations to investigate structural and transport properties of these active spinner materials, the findings will provide insight into properties

of synthetic active spinner materials for particle transport and manipulation at the microscale.

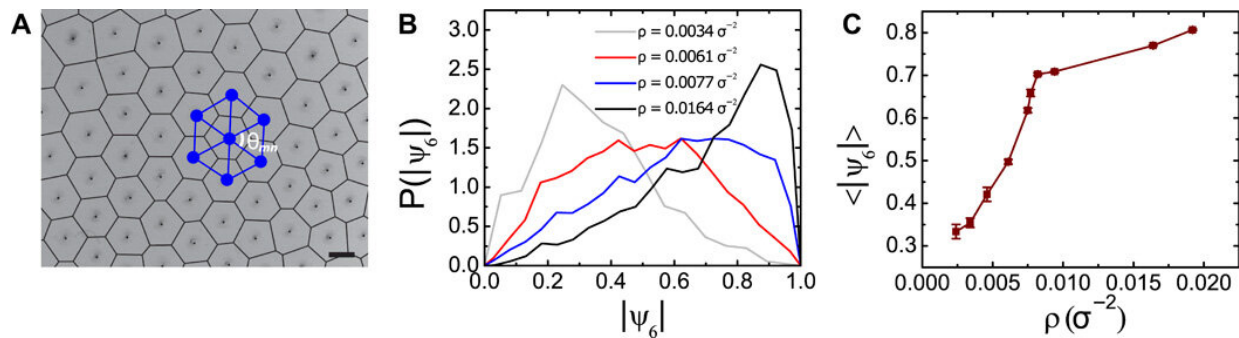


Magnetic field–driven assembly of multiparticle spinners. (A) Schematics of a dispersed state of Ni particles under a static magnetic field along the z direction. (B) Assembly of spinners under influence of a rotating magnetic field applied in the xy plane (the bottom snapshot is a representative experimental image). (C) Spinner size as a function of field frequency f_H at $\rho = 0.006 \sigma^{-2}$. The chain length, L_S , is normalized by the particle diameter, σ ($90 \mu\text{m}$). The solid line is a calculated theoretical curve. Inset: Reynolds number, Re , of the spinners as a function of f_H . Credit: Science Advances, doi: 10.1126/sciadv.aaz8535

The team applied a static magnetic field perpendicular to the air-water interface to allow dynamic self-assembly of spinners from suspended ferromagnetic nickel particles. They energized the system using an external rotating magnetic field applied in-plane with the interface. The

self-assembly of spinners was fully reversible and controlled via parameters of the external field, to assemble magnetic-field driven multiparticle spinners into nearly [lattice](#)-like structures. The magnetic spinners described in the experiments and simulations differed in two important aspects from [previously designed rotating discs](#). Specifically, (1) magnetic attraction between the particles were strong enough to overcome the repulsion and form chains, and (2) the high [anisotropy](#) of spinners allowed the flow field to vary periodically in time.

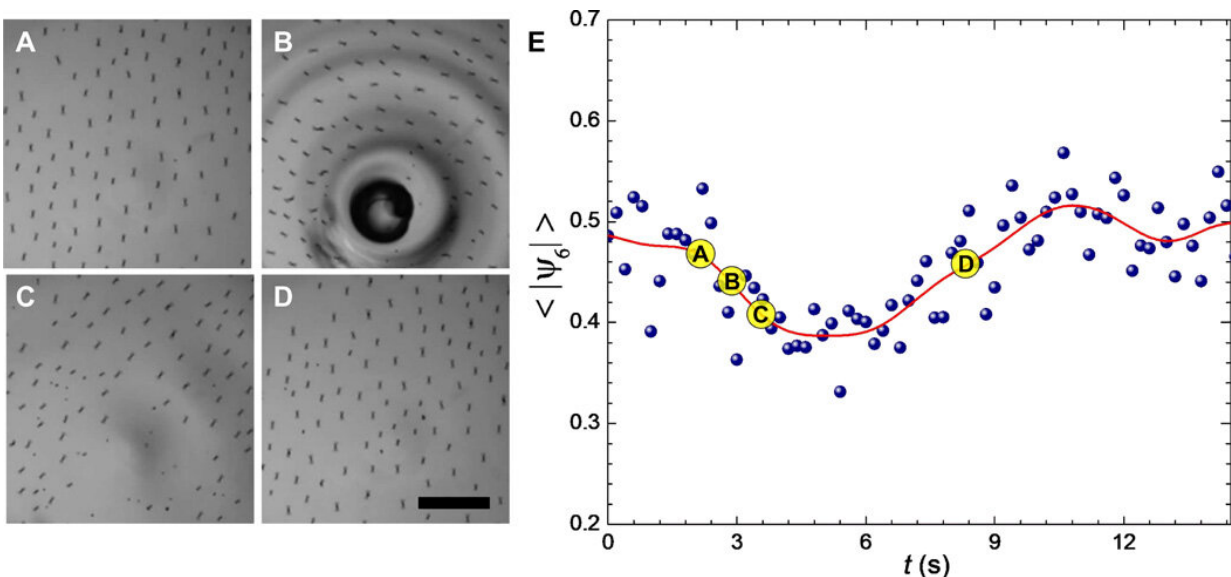
Han et al. noted large ensembles of the synchronized self-assembled spinners to exhibit dynamic self-organization and calculated the hexagonal bond-oriented order to quantify local ordering of the spinners. Changes in the mean value of the hexagonal bond-order parameters of spinner lattices revealed a clear transition from the liquid phase to the crystalline phases with increasing spinner density. At low density, the spinners retained liquid-like behavior—as the density increased, they became more restricted in their motion to form self-organized spinner lattices.



The local ordering of the experimentally obtained spinner lattices. (A) A dynamic lattice formed from spinners at $fH = 45$ Hz and $\rho = 0.0164 \sigma^{-2}$. Voronoi diagram is overlaid with the observed lattice. The spinners are blurred because of the long exposure time that enabled precise identification of the rotational axes for all spinners. Scale bar, 1 mm. (B) The probability distribution

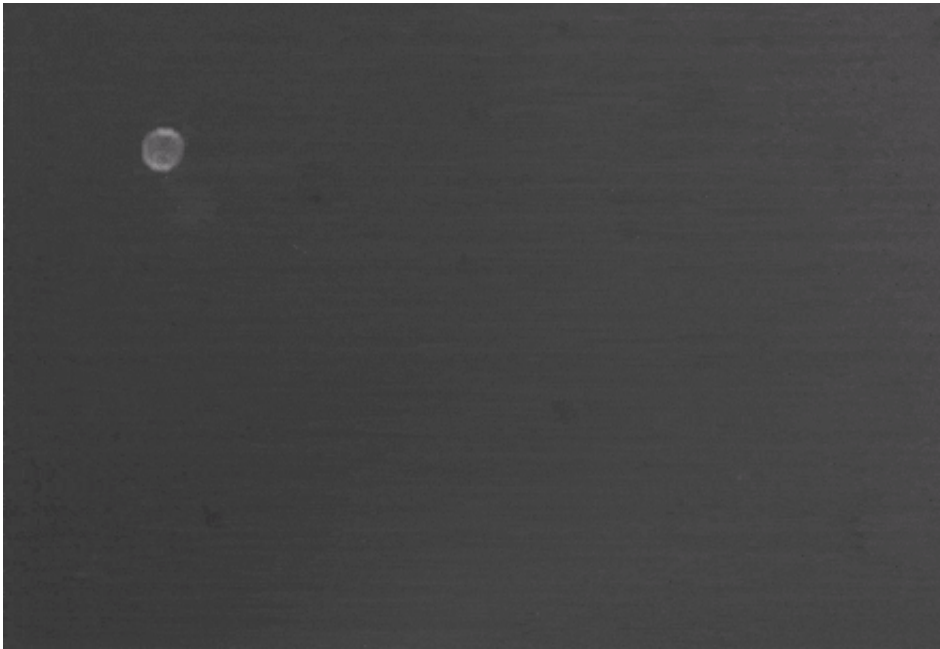
of the hexagonal bond-orientational order parameter $|\psi_6|$ in the spinner lattices at $fH = 45$ Hz as a function of ρ . (C) The mean ψ_6 value of the spinner lattices illustrates the liquid-to-crystalline dynamic phase transition with the spinner density ρ . Credit: Science Advances, doi: 10.1126/sciadv.aaz8535

The simulations similarly captured the liquid-like order of spinners at low densities although their transition to solids were not as pronounced compared to the experiments. To further investigate and characterize the structural order of the dynamic spinner lattices in detail, the team analyzed the relative positions of the spinners within the ensemble and observed the spinners to self-organize into lattices with well-defined frequency-dependent inter-spinner spacing at high densities. The lattices of synchronized spinners formed a new class of active crystals accompanied by a vigorous [vortical flow](#) field. The self-organized spinner lattices retained self-healing capacity, which Han et al. showed by intentionally destroying the spinner lattice with a large glass bead passing through its interface—once the bead had passed through the interface, the affected spot self-repaired in a few seconds.



Self-healing behavior in active spinner lattices. (A to D) Snapshots of a spinner lattice demonstrating the self-healing process: (A) A spinner lattice at $f_H = 90$ Hz, $\rho = 0.0112 \sigma^{-2}$, (B) the moment of the lattice rupture by a 3-mm bead, (C) the lattice is locally fractured by the bead, and (D) spontaneously self-repaired lattice. Scale bar, 5 mm. (E) The time evolution of the mean bond orientational order parameter ψ_6 in the fractured region of the spinner lattice. Credit: Science Advances, doi: 10.1126/sciadv.aaz8535

The strong self-induced underlying hydrodynamic flows indicated the possibility for a lattice of synchronized spinners to effectively transport passive cargo particles. To characterize this, the scientists determined the [diffusion coefficient](#) for a passive nonmagnetic particle placed inside a dynamic spinner lattice by tracking its [mean square displacement](#) (MSD). They referred to particle transport as active diffusion—since the results were orders of magnitude greater than those corresponding to passive thermal [Brownian motion](#). They efficiently tuned the active diffusion coefficient based on the external field frequency. The behavior of the system contributed to changes in spinner-spinner distances within the lattice to form a caging effect on a passive cargo bead and prevent its exit from the cell. Much like with the experiments, the simulations showed enhanced motion and diffusion for small and large tracer particles, however, Han et al. did not observe frequency dependence for the diffusion coefficient during the simulation compared to experiments. The scientists therefore suggest using three-dimensional (3-D) simulations to clarify the origin of the observed discrepancy.



Active transport of a 500- μm glass bead facilitated by a spinner lattice, as obtained in experiments. Credit: Science Advances, doi: 10.1126/sciadv.aaz8535

In this way, Koohe Han and colleagues reported the results of structural and transport properties of a new active material composed of self-assembled, synchronized spinners. They suspended ferromagnetic microparticles at an air-water interface for dynamic self-assembly into multiple spinners powered by a rotating [magnetic field](#) applied at the interface. The activity of the system originated due to the rotational motion of spinners, unlike conventional active systems composed of self-propelling units. Collective interactions between spinners allowed the formation of new dynamic phases including spinner liquids and self-organized lattices that supported active diffusion through robust, self-generated hydrodynamic flows, alongside self-healing behavior. The team showed the possibility of transporting inert cargo particles within self-organized active spinner lattices with remote control and manipulation. These applications of synchronized spinner swarms will provide new opportunities to design self-assembled structures and

tunable transport in active materials at the microscale.

More information: Koohee Han et al. Reconfigurable structure and tunable transport in synchronized active spinner materials, *Science Advances* (2020). [DOI: 10.1126/sciadv.aaz8535](https://doi.org/10.1126/sciadv.aaz8535)

Alexey Snezhko et al. Magnetic manipulation of self-assembled colloidal asters, *Nature Materials* (2011). [DOI: 10.1038/nmat3083](https://doi.org/10.1038/nmat3083)

Bartosz A. Grzybowski et al. Dynamic self-assembly of magnetized, millimetre-sized objects rotating at a liquid–air interface, *Nature* (2002). [DOI: 10.1038/35016528](https://doi.org/10.1038/35016528)

© 2020 Science X Network

Citation: Reconfigurable structure and tunable transport in synchronized active spinner materials (2020, March 27) retrieved 24 April 2024 from <https://phys.org/news/2020-03-reconfigurable-tunable-synchronized-spinner-materials.html>

This document is subject to copyright. Apart from any fair dealing for the purpose of private study or research, no part may be reproduced without the written permission. The content is provided for information purposes only.