nature

NEWS AND VIEWS | 04 August 2021

Bouncing droplets mimic spin systems

Experiments show that a collection of bouncing fluid droplets can behave like a microscopic system of spins – the intrinsic angular momenta of particles. This discovery could lead to a better understanding of the physics of spin systems.

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In 2005, researchers found that bouncing fluid droplets on the surface of a vibrating liquid bath can self-propel[1]. Remarkably, the dynamical and statistical features of this macroscopic system resemble those of microscopic quantum systems. Building on this work, Sáenz *et al.*[2] report in *Nature* that arrays of bouncing droplets can mimic systems of spins (the intrinsic angular momenta of particles). The authors' discovery could increase knowledge of these spin systems, which have uses in spin-based electronics and computing.

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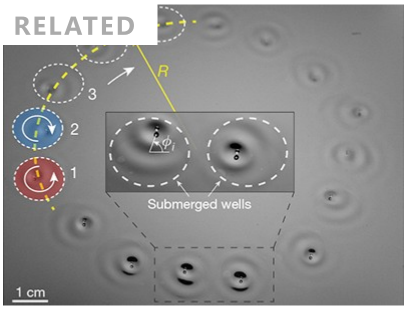

Read the paper: Emergent order in hydrodynamic spin lattices

In their quest for a better understanding of the emergence of order in typically disordered systems, physicists have developed many models in fields ranging from animal behaviour to materials science. A few of these models have become archetypes that are taught today in advanced physics courses. Let us consider two of them.

The first model concerns the dynamical synchronization of oscillators, which is described in every textbook on nonlinear physics[3] – the study of systems in which cause and effect are not directly proportional to each other. Such synchronization is often illustrated by considering the flashing of fireflies. In the model, when one firefly sees others flashing nearby, it speeds up or slows down its own flashing to be in sync with its neighbours. This behaviour explains why, in some areas of south Asia, the synchronicity of fireflies that land on trees at dusk builds up during the night, as shown in an acclaimed 1990 BBC nature documentary series, *The Trials of Life*. In the model, the collective flashing of fireflies results from their subtle interactions mediated by light.

The second model, from statistical physics, is known as the spin model[4]. It was introduced to study ferromagnetism — the familiar type of magnetism found in iron magnets. In the model, spins are arranged on a lattice that is in thermal equilibrium with a reservoir of heat called a thermal bath. A spin can point either up or down. As with the fireflies, complex physical behaviour emerges when each spin is influenced by its neighbours.

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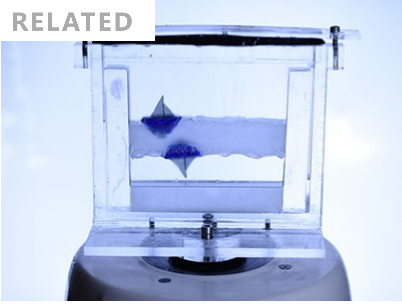

Vibration overcomes gravity on a levitating fluid

The competition between thermal agitation and spin alignment leads to a transition between ordered phases (for strong spin–spin interactions at low temperature) and disordered phases (for weak spin–spin interactions at high temperature). In the ordered phases, the overall symmetry of the spin lattice is broken because the pattern of spins would look different if flipped upside down, whereas in the disordered phases, such symmetry is retained. The properties of this system are therefore governed by the interactions between spins. The ordered phases can correspond to ferromagnetism, in which spins point in the same direction, or antiferromagnetism, in which neighbouring spins point in opposite directions.

Following on from pioneering work[1,5], Sáenz and colleagues studied fluid droplets bouncing on the surface of a vertically vibrating liquid bath (Fig. 1a). For particular values of the vibration amplitude and frequency, close to those associated with a surface instability called the Faraday instability, each bounce of the droplets generates a surface wave that causes the droplets to self-propel. Furthermore, these surface waves eventually reach other bouncing droplets, inducing non-trivial droplet–droplet interactions and triggering complex droplet trajectories. Collections of such droplets form aggregates of interacting bouncing entities. Two droplets can bounce in sync or out of sync with each other[5]. And in some cases, more than two bouncing droplets can share a single surface wave that exhibits a phenomenon known as coherence[6].

Figure 1

Figure 1 | A system of bouncing droplets. a, Sáenz *et al.*[2] studied the behaviour of fluid droplets bouncing on the surface of a vertically vibrating liquid bath. The depth of the bath varied owing to the presence of submerged wells. Under certain conditions, the droplets generated gradually decaying surface waves that caused the droplets to follow clockwise or anticlockwise circular trajectories and interact with each other in complex ways. **b**, The authors found that arrays of these bouncing droplets (pictured) share many features with systems of spins — the intrinsic angular momenta of particles. Scale bar, 1 centimetre. (Adapted from Fig. 1b and Fig. 4a of ref. 2.)

Sáenz and co-workers considered submerged wells that locally change the depth of the liquid bath. Because these depth variations influence the propagation of the surface waves, the bouncing droplets are piloted along specific paths. In particular, circular submerged wells cause the droplets to follow clockwise or anticlockwise circular trajectories. By analogy with magnetic spin, the spin of such a droplet can be defined as the angular momentum of the droplet's horizontal motion: down for clockwise motion and up for anticlockwise motion.

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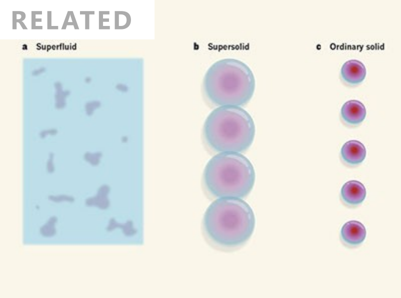

Quantum gases show flashes of a supersolid

The authors found that when these circular wells are arranged on a one- or two-dimensional lattice with a small (millimetre-scale) lattice spacing, the droplets can be affected by the surface waves emitted by neighbouring droplets (Fig. 1b). Depending on the lattice shape and dimensions, and the experimental conditions, the pattern of droplet spins can resemble the arrangement of magnetic spins in ferromagnetism or antiferromagnetism, meaning that symmetry is broken spontaneously. This ordering of droplet spins emphasizes the complex wave-interaction mechanism that is mediated across the lattice. In spectacular experiments, Sáenz *et al*. discovered that a global angular momentum can be imposed on the system, similar to the way in which an external magnetic field aligns spins and thereby magnetizes materials.

Sáenz and colleagues' work demonstrates that arrays of these droplets can synchronize their bouncing vertical motion just as fireflies synchronize their light flashes. Moreover, it shows that the droplet spins can exhibit pattern formation and symmetry breaking, similar to those seen in magnetic-spin lattices, through subtle hydrodynamic interactions. The system therefore seems to combine the two archetypal models mentioned previously.

Although the hydrodynamic spin lattices presented share many features with magnetic-spin systems, the former are out of equilibrium whereas the latter are in equilibrium, suggesting that the observed synchronized behaviour might be universal. Sáenz and colleagues' experiments used a limited number of bouncing droplets (fewer than 50), but the authors model larger systems that could be explored in future numerical studies. There is little doubt that these hydrodynamic spin lattices will inspire research at the intersection of statistical physics, nonlinear physics and fluid mechanics.

Nature **596**, 40-41 (2021)

doi: https://doi.org/10.1038/d41586-021-02077-6

References

1. Couder, Y., Protière, S., Fort, E. & Boudaoud, A. *Nature* **437**, 208 (2005).
2. Sáenz, P. J. *et al. Nature* **596**, 58–62 (2021).
3. Strogatz, S. H. *Nonlinear Dynamics and Chaos* (CRC Press, 2018).

4. Stanley, H. E. *Introduction to Phase Transitions and Critical Phenomena* (Oxford Univ. Press, 1971).

5. Eddi, A., Decelle, A., Fort, E. & Couder, Y. *Europhys. Lett.* **87**, 56002 (2009).

6. Filoux, B., Hubert, M. & Vandewalle, N. *Phys. Rev. E* **92**, 041004 (2015).

COMPETING INTERESTS

The author declares no competing interests.

Nature (*Nature*) | ISSN 1476-4687 (online) | ISSN 0028-0836 (print)