**Britta Engelhardt** is at the Theodor Kocher Institute, University of Bern, CH-3012 Bern, Switzerland.
e-mail: bengel@tki.unibe.ch

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Fluid dynamics

# Bouncing droplets mimic spin systems

## Nicolas Vandewalle

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. **See p.58**

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 on page 58 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.

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.

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].

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

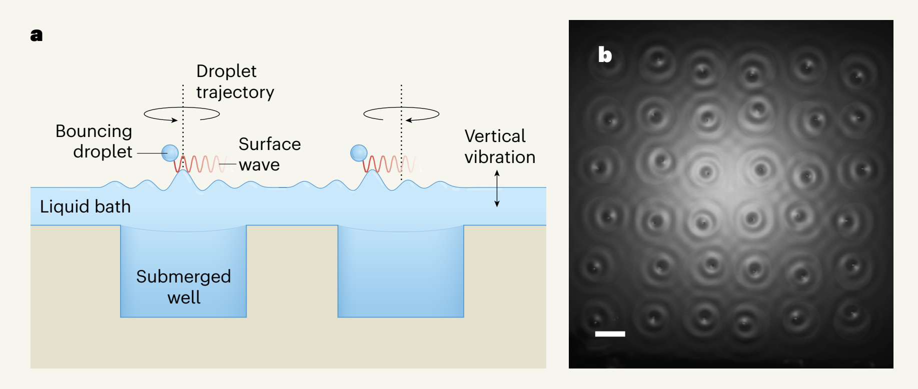

**Figure 1 | A system of bouncing droplets. a**, Sáenz *et al.*[2] studied the behaviour of fluid droplets bouncing on the surface of a vertically vibrating liquid bath. The depth of the bath varied owing to the presence of submerged wells. Under certain conditions, the droplets generated gradually decaying 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.)

angular momentum of the droplet's horizontal motion: down for clockwise motion and up for anticlockwise motion.

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.

**Nicolas Vandewalle** is at the GRASP Laboratory, Department of Physics, University of Liège, 4000 Liège, Belgium.
e-mail: nvandewalle@uliege.be

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## From the archive

**An account of the unveiling of the theory of natural selection, and a reported sighting of an unusual type of lightning.**

### 50 years ago

It is a truth of history and an aspect of human behaviour that momentous occasions recalled in later life ... often gain in grandeur and importance with the passing of time. A study of contemporary documents by J. W. T. Moody (*J. Soc. Bibliog. Nat Hist.*, **5**, 474; 1971) shows that the presentation of the Darwin–Wallace papers on natural selection to the scientific world on July 1, 1858, was no exception ... [T]he occasion has been said to represent the beginning of a new era in scientific thinking ... but at the time of its presentation it was something of a non-event. [T]he meeting at the Linnean Society ... had been specially called by the president for the election of a new council member ... [T]he secretary read the text of the Darwin and Wallace papers ... Darwin for domestic reasons did not attend the meeting ...[A]t that date agenda were not sent to members, so the fewer than thirty members who attended ... can hardly have expected a momentous meeting ... Moody ... suggests that the audience were not so much stunned by new ideas as they were overwhelmed by the sheer volume of information loaded upon them. No formal discussion took place at the meeting, the audience was expected to switch its attention instantly from the Darwin–Wallace papers to "Notes on the organization of *Phoronis hippocrepis*".

**From *Nature* 6 August 1971**

### 100 years ago

A description of ball lightning seen in the sky at St. John's Wood during a thunderstorm in the early morning of June 26 has recently been received at the Meteorological Office. The phenomenon, a large incandescent mass floating in the air below the clouds and apparently stationary for some minutes, is of great rarity, and the Director of the Meteorological Office, London, S.W.7, would be greatly obliged if persons who observed it on this occasion would communicate with him.

**From *Nature* 4 August 1921**

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Structural biology

# Two giants of cell division in an oppressive embrace

**Silke Hauf**

**The enzymes separase and cyclin-dependent kinase are key orchestrators of cell division. Structural data reveal the surprisingly intricate mechanism that renders them both inactive when bound to each other. See p.138**

In every dividing cell, a time comes when the two copies of the genome need to be separated. The aptly named enzyme separase springs into action and gets the job done. Unleashing separase at any other time in the life of a cell would be dangerous, so the enzyme is kept well guarded. Human separase is held in check by not one but three mutually exclusive inhibitors. On page 138, Yu *et al.*[1] report structures of human separase in complex with two of these inhibitors. The structures show commonalities but also striking differences. One of the inhibitors snakes along separase to embed itself in the enzyme's active site. The other forces separase to inhibit itself; at the same time, this inhibitor is itself inhibited by separase in an entangled embrace.

Cell division is studied both for its beauty and for the danger that it represents. When all goes well, new healthy cells are born. But when things go awry, newborn cells inherit faulty copies of the genome and might die or become the seed for cancerous growth. Movies of cell division showing this dramatic process never fail to intrigue, and such films have provided an inspiration that has launched renowned scientific careers (see, for example, ref. 2). In the key scene of cell-division movies, chromosomes split abruptly along their length, separating the two copies of