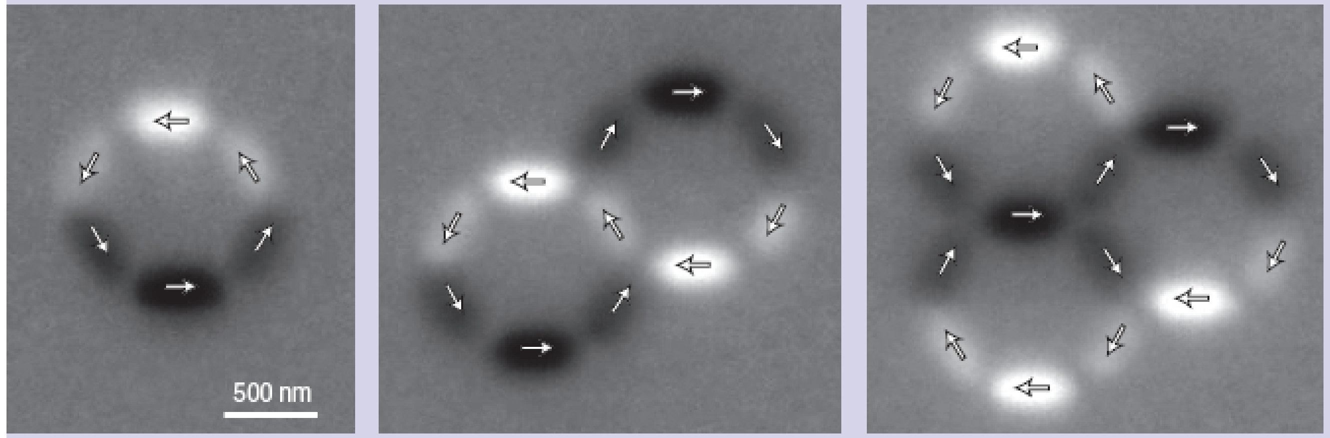
ARTIFICIAL SPIN ICE

Increasingly frustrated



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The properties of a large system can sometimes be elegantly rationalized by considering only simple concepts that govern the system as a whole; a deep understanding might, however, require details of how its smaller subsystems behave. A case in point is the study presented in *Physical Review B* by Elena Mengotti and colleagues, in which they look at the building blocks of an artificial spin-ice system and show how the characteristic behaviour of these systems emerges (*Phys. Rev. B* **78,** 144402; 2008).

Spin ice describes a phase of magnetic systems in which, owing to geometric frustration, the ground state is disordered — and therefore possesses non-zero entropy — even when approaching zero temperature. A number of natural systems show such peculiar behaviour, but progress in lithographic patterning techniques has made it possible to create artificial spin ice, based on two-dimensional arrays of single-domain ferromagnetic islands. Following this line of work, Mengotti *et al.* have studied a kagome lattice, in which the magnetic islands form the edges of a honeycomb structure.

The magnetic moment of each island can be either parallel or antiparallel to its long axis, and the energetically most favourable configuration is one in which the magnetization vectors of neighbouring islands meet head-to-tail. That's fine for a single ring of islands, but not for two or more linked rings, because there are vertices at which three islands interact. At these points, the magnetic moments cannot be arranged such that each couple forms a head-to-tail pair — the system becomes 'frustrated'. The best compromise is to have two moments pointing towards the vertex, and one away from it, or *vice versa*. But for an extended honeycomb network, there are a huge number of equivalent arrangements that satisfy this two-in–one-out rule at each vertex, and, as a consequence, the ground state is disordered.

Mengotti and colleagues' interest is in the one- to three-ring building blocks of such networks. For these geometries, they calculated the energies of all possible magnetic configurations — which is possible for these systems, but becomes intractable for larger arrays — pinpointed the states with lowest energy and compared them with experimental observations. Following demagnetization of the sample, almost all of the single rings were found in the lowest-energy configuration, with all islands in a head-to-tail configuration (as seen in the X-ray magnetic circular dichroism images here, in which brightness shows magnetization direction). In the two- and three-ring systems, however, frustration appears at the corners and for these geometries only about a half or a third of all samples, respectively, end up in the lowest-energy state. The implication is that, for a large network based on such building blocks, it might be practically impossible to reach the ground state.

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