Artificial spin ice on the CaVO lattice: a bridge from square to kagome

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Artificial spin ices are arrangements of dipolar-coupled nanomagnets, with magnetic moments that behave like Ising spins as a result of shape anisotropy. They have been successfully implemented as platforms for imaging and controlling phase transitions in systems with long-range interactions [1]. However, the exploration of thermally-activated phase transitions has been mostly focused on two lattices: the square and the kagome. Artificial square ice orders readily into an antiferromagnetic, two-in/two-out ground state, with a transition belonging to the Ising 2D universality class [2]. In contrast, artificial kagome ice is highly frustrated and the predicted phase diagram is richer [3, 4]. Upon lowering the temperature, the system first experiences a crossover from a paramagnetic to a spin liquid state with no long range order, then transitions into a Coulomb phase with charge crystallization. This is an example of magnetic moment fragmentation [5, 6], in which each magnetic moment can be decomposed into the sum of a long-range ordered, divergence-full fragment and a fluctuating, divergence-free fragment which can be elegantly mapped to a dimer model.

We have carried out a comprehensive characterization of the thermodynamics of an artificial spin ice based on the CaVO (also called the square-octagon) lattice, part of the family of Archimedean lattices [7]. We show that the magnetic interactions on the vertex level can be significantly tuned by changing the relative sizes of square and octagonal plaquettes, while preserving the lattice constant and symmetries. This results in a complex phase diagram, with two very different ground states and ordering processes separated by a multicritical region. Each bears strong similarities with either the square or kagome phenomenologies. We map out this phase diagram with Monte-Carlo simulations and magnetic force microscopy of as-grown configurations. Different spin liquid states can be observed, as well as moment fragmentation for some geometries. Finally, we perform temperature and field-dependant magnetometry measurements on a series of lattice geometries, making it possible to detect thermally-active correlated phases without using large-scale instrumentation. Our work paves the way for engineering exotic magnetic properties at the mesoscale. By tuning frustration within a single lattice geometry, we can design artificial systems that exhibit spin liquid and multicritical behaviours - something that, in natural magnetic systems, typically requires extremes of either pressure, field or temperature.

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