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Realizing Colloidal Artificial Ice on Arrays of Optical Traps

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In certain spin models, the geometric spin arrangements frustrate the system since not all of the nearest neighbor spin interaction energies can be minimized simultaneously. A classic example of this is the spin ice system, named after the similarity between magnetic ordering on a pyrochlore lattice and proton ordering in water ice. Spin ice behavior has been observed in magnetic materials such as $Ho_2Ti_2O_7$, where the magnetic rare-earth ions form a lattice of corner-sharing tetrahedra. The spin-spin interaction energy in such a system can be minimized locally when two spins in each tedrahedron point inward and two point outward, leading to exotic disordered states. There are several open issues in these systems, such as whether long range interactions order the system, or whether the true ground state of spin ice is ordered. We demonstrate how a colloidal version of artificial ice and other frustrated configurations can be realized using charged colloidal particles in arrays of elongated optical traps. Using numerical simulations, we show that this system obeys the ice rules of two-spins-in, two-spins-out at each vertex. We find a transition between a random configuration and a long-range ordered ground state as a function of colloid charge, trap size, and screening length. We show that both the ice rule ordering and a thermally-induced order-disorder transition can occur for systems with as few as 24 traps and that the ordering transition can be observed at constant temperature by varying the barrier strength of the traps. This system can also be used to explore various other types of ordered and frustrated systems with different lattice geometries, such as a honeycomb lattice which prevents the formation of a long-range ordered ground state. Similar effects should occur for vortices in type-II superconductors interacting with elongated arrays of blind holes. Experimental versions of frustrated colloidal systems could allow for direct visualization of the dynamics associated with frustrated spin systems, such as deconfined or confined spin arrangements, as well as spin dynamics at melting transitions. [1] A. Libál, C. Reichhardt, and C.J. Olson Reichhardt, Phys. Rev. Lett. 97, 228302 (2006).