Quantum Ice

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Water ice comprises a loosely-packed lattice of water molecules, held together by hydrogen bonds. This is a very stable structure, but one with a hidden puzzle — chemical bonding alone does not select a unique orientation of the water molecules. As a result *each* water molecule has a finite ground state entropy $s_0 \approx k_B \log(3/2)$, in violation of the laws of thermodynamics. Exactly the same degeneracy, and the same contradiction, arises problems of frustrated charge order on the pyrchlore lattice, and in the family of rare-earth magnets collectively known as spin ice.
Here we use zero-temperature quantum Monte Carlo simulations to explore how quantum mechanical tunneling between different spin- or charge-ice configurations can lead to a resolution of this issue, by stabilizing a unique "quantum ice" ground state. This quantum ice state has excitations described by the Maxwell action of 3+1-dimensional quantum electrodynamics, and so retains the algebraic correlations and deconfined fractional excitations (magnetic monopoles) associated with classical (spin) ice states.