Theory of quantum spin ice for realistic magnetic pyrochlore oxides

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Recent experimental observations of quantum effects in variants of classical spin ice have urged intensive and extensive theoretical studies. Here, we derive a realistic quantum pseudospin-1/2 model for magnetic pyrochlore oxides characterized by Kramers/non-Kramers magnetic doulets of rare-earth ions, including Pr_2TMO_7 (TM = Zr, Sn, Hf, Ir) and Yb_2TMO_7 (TM = Ti, Sn). It contains three/two quantum-mechanical nearest-neighbor coupling constants of the superexchange origin, which appreciablly reduce the symmetry of the model from U(1). Then, the model is investigated both analytically and numerically in comparison with experimental findings on the neutron-scattering profile and the magnetization curve. Various non-trivial quantum phases are found within a realistic range of the coupling constants, including an emergent U(1) spin liquid and dipole/quadrupolar orders. Role of quantum effects on magnetic monopoles are also discussed.