Theory of Spin-Lattice Interaction in a Quantum Spin Ice

Abstract:

$Tb_2Ti_2O_7$ (TTO) is an Ising like frustrated pyrochlore magnetic material not showing any magnetic order down to 50 mK despite to the Curie-Weiss temperature of about -13 K. This compound has been considered as a potential candidate for the realization of quantum spin ice (QSI). However, despite two decades of intense experimental and theoretical research, the true nature of its quantum ground state remains unsolved. While the main focus of the recent researches has been on the magnetic properties, TTO primarily attracted the interests because of its unusual elastic properties. The low-temperature magnetostriction measured for this compound is 2-3 order of magnitude larger than the other lanthanide series such as Ho, Dy, and Yb and it has been discussed that the origin of such a giant magnetostriction is basically a single-ion effect, caused by the intermixing of the ground doublet with its nearby excited doublet by the external magnetic field. We develop a theory for the spin-lattice coupling through magneto-elastic interaction in a quantum spin ice. We study the coupling of single ion ground doublet to both inversion even and inversion odd optical phonons. We show that the neither the dynamic John-Teller (linear spin-lattice coupling to even inversion phonons), nor the dynamic Renner-Teller coupling (quadratic coupling to inversion odd phonons) are able to split the ground doublet. We calculate the low-lying magneto elastic modes for John-Teller and Renner-Teller couplings for a single ion and also propose a phonon-mediated mechanism for spin-spin exchange interactions.