The Physics of Spin Ice

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Spin ice is the most vivid realisation of a general class of condensed matter that is highly correlated, yet lacks conventional order. It is named after water ice, H2O, in which the protons (H+) form a macroscopically degenerate low temperature state that is characterised by the Pauling zero point entropy. In spin ice materials such as Ho2Ti2O7 and Dy2Ti2O7 there is a 1:1 mapping between the configurations of the Ho or Dy "spins" and the proton configurations of water ice : hence these materials also show the Pauling entropy and nearly all the other properties of "ideal" water ice, a 16-vertex model.

In fact spin ice is the first experimental realisation of a vertex model for which the full phase diagram can be mapped out experimentally, by adjusting the vertex weights with an applied magnetic field. However, to obtain a full description of the experimental properties of spin ice, one needs to incorporate the effect of the long range dipole-dipole interaction. When this is done, one finds a remarkable result: the spin-ice to water ice mapping is valid not only that the level of statistical mechanics, but also at the level of electrodynamics. Thus, while water ice is a weak electrolyte that contains mobile electrical charges (protons or proton holes), spin ice is a weakly dissociated magnetic Coulomb gas that contains mobile magnetic charges, or monopoles. These magnetic charges are quantised, deconfined and nearly point-like.

In this lecture I will review the physics of spin ice and highlight recent experimental work that has demonstrated the the magnetic equivalent of electricity ("magnetricity") in spin ice, including measurement of the "elementary" magnetic charge, and the experimental distinction of free and bound magnetic monopole currents.