The European Physical Society

2012 EPS Condensed Matter Division Europhysics Prize
Long Citation

The 2012 EPS Condensed Matter Division Europhysics Prize is awarded to Steven Bramwell, Claudio Casternovo, Santiago Grigera, Roderich Moessner, Shivaji Sondhi and Alan Tennant for the prediction and experimental observation of magnetic monopoles in spin ice. The Prize will be presented at the forthcoming EPS CMD General Conference in Edinburgh (UK).

Among the most exotic and unexpected developments in recent decades has been the discovery that collective excitations in some strongly interacting systems have quantum numbers that are a fraction of those carried by the indivisible constituent particles. Up till this work fractionalization has been restricted to one and two dimensions with examples in both quantum and classical systems. Among the better known examples are the solitons in polyacetelyne which can carry the charge of an electron but not the spin, and the fractionally charged quasiparticles in the Fractional Quantum Hall systems. Now for the first time fractionalization has been found in a three dimensional classical system leading to the unexpected appearance of free magnetic monopoles. In electromagnetism there is a fundamental asymmetry between the deconfined individual electric monopole charges and magnetic charges confined in pairs to form magnetic dipoles. Now for the first time a special system has been discovered, where the magnetic dipoles are fractionalized, or broken apart, into a pair of freely moving magnetic charges.

This phenomenon occurs in a highly frustrated pyrochlore lattice of rare earth magnetic ions, known as spin ice. The name arises from the close analogy between the rule governing the lowest energy configuration in ice, namely the presence of 2 close by and 2 further hydrogen ions surrounding each oxygen in ice, and the rule here that 2 of the 4 spin dipoles on the rare earth ions located at the corners of each tetrahedron, point inward, and 2 point outward. This ice rule is satisfied by a macroscopic number of configurations leading to the famous finite zero point entropy in both ice and spin ice. The fractionalization follows in spin ice from the simplest excitation with an overturned single spin which creates a nearest neighbour pair of tetrahedra,one with 3 spins pointing inward, 1 out and the second with 3 outward, 1 in. The large entropy allows these two spin configurations to separate and move independently generating a pair of elementary excitations. This splits the magnetic dipole into a pair of magnetic monopoles. In an elegant paper, Castelnovo, Moessner and Sondhi derived a gauge field theory for spin ice and demonstrated that this field theory can exhibit a deconfined phase in which free monopoles appear as pairs. The proliferation of tetrahedra which violate the 2 in and 2 out constraint, leads to a magnetic analogue of an electrolyte with emergent magnetic monopoles.

The prediction of free magnetic monopoles was rapidly verified in a series of beautifully conceived experiments. Bramwell and coworkers exploited the analogy to the electrolyte to observe the magnetic version of the Wien effect whereby the increase in the density of magnetic monopoles in an applied magnetic field, was monitored by the spin relaxation rate of injected spin polarized muons. Both Bramwell and colleagues and Grigera, Tennant and colleagues used neutron scattering to examine the magnetic fluctuation spectrum in detail. The latter group studied the diffuse neutron scattering spectrum in spin ice dysprosium titanate to demonstrate the existence of "Dirac Strings" which connect the free monopoles, by manipulating the density and orientation of these strings in an external magnetic field. In addition, they showed that the heat capacity could be nicely explained as a gas of magnetic monopoles interacting via a magnetic Coulomb potential. Complementary corroborative evidence of the emergent gauge field structure was obtained by the former group by studies of the special 'bow tie' form of the magnetic structure factor using spin polarized neutron scattering in the holmium titanate.

The magnetic monopoles in spin ice are the first examples of a fractionalized excitation in three dimensions. Their existence was predicted by an elegant and compelling gauge theory and confirmed by convincing sophisticated experiments. The demonstration that magnetic dipoles can be broken into free magnetic monopoles comes as a surprise which has attracted the attention of a wider audience, not just specialists. It will surely be a poster child for the fractionalization phenomenon in future textbooks.