NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Magnetic monopoles and out-of-equilibrium properties of spin ice

General Scope :

In the presence of competing energies, matter tries to adapt by stabilizing novel states. In magnetism, the competition between magnetic interactions can create magnetic states different from conventional ferromagnetic or antiferromagnetic ordered states, and which remain disordered down to the limit of absolute zero of temperature. The far-from-equilibrium physics of such low temperature states may be even more exotic, yet to access it in the laboratory remains a challenge.

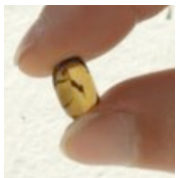

Fig. 1: A $Dy_2Ti_2O_7$ spin ice sample.

"Spin ice" is an example of such a state where the magnetism is governed by local rules giving rise to a ground state degeneracy, and whose excitations can be described as magnetically charged quasiparticles, called magnetic monopoles [1]. It is realized in pyrochlore (=corner sharing tetrahedron lattice) compounds $Dy_2Ti_2O_7$ (Fig. 1) and $Ho_2Ti_2O_7$ below about 2 K.

At very low temperature, deep in the spin ice regime (below 500 mK), the equilibirum density of magnetic monopoles tends towards zero. The system enters an out-of-equilibrium regime where the dynamics are governed by the motion of monopoles (Fig. 2). In particular, we have shown that quenching a high density of monopoles at low temperature significantly modifies the dynamics [2]. Nevertheless, the nature of the out-of-equilibrium state is poorly understood.

We have recently developed a set-up able to measure the magnetic fluctuations and the ac susceptibility down to 100 mK, which allows us to test the fluctuation-dissipation relation, and thus to directly probe the out-of-equilibrium state of spin ice. Our preliminary measurements are extremely promising.

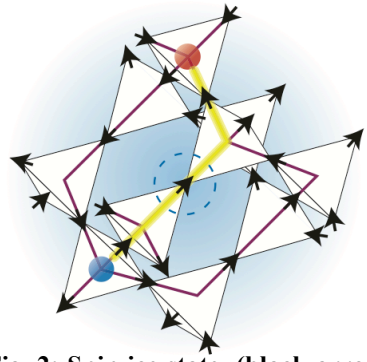

Fig. 2: Spin ice state (black arrows) on a pyrochlore lattice with 2 magnetic monopoles moving around (red / blue spheres). From Moessner, Nature Phys. 5 (2009).

[1] for a brief introduction see Science **326**, 375 (2009), arXiv: 1005.3557

[2] C. Paulsen *et al*., Nature Physics **10**, 135 (2014); Nature Physics **12**, 661 (2016); Nature Comm. **10**, 1509 (2019)

Research topic and facilities available :

The objective of the internship is to measure the magnetic noise and the ac susceptibility of two spin ice samples $Dy_2Ti_2O_7$ and $Ho_2Ti_2O_7$ as a function of temperature and frequency, using different experimental protocols in order to vary the density of monopoles. From these measurements, the student will determine the fluctuation-dissipation relation, and compare it with theoretical predictions. Experiments will be performed using the magnetic noise set-up recently developed in the team and equipped with a He^3-He^4 dilution refrigerator to reach subKelvin temperatures.

Possible collaboration and networking : S. T. Bramwell and S. R. Giblin (UK), with the theoretical support of P. C. W. Holdsworth (ENS Lyon).

Possible extension as a PhD : yes

Required skills: Master 2 in Physics

Starting date : from the beginning of 2022

Contact : Elsa Lhotel
Institut Néel - CNRS
Phone : 33-(0)4.76.88.12.63. e-mail : elsa.lhotel@neel.cnrs.fr

More information : http://neel.cnrs.fr