Experiment Proposal

Experiment Number: 910392

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Experiment Title The search for magnetic monopoles in spin ice.
Instrument **MUSR** **Days Requested:** 4
Access Route Direct Access - New **Previous RB Number:** -
Science Areas Physics
Sponsored Grant No **Sponsor:** -
Grant Title -
Grant Number -
Start Date: - **Finish Date:** -
EU Access? No
Similar Submission? No

Abstract

In recent work Moessner and colleagues have demonstrated that thermally induced defects in spin ice behave as emergent magnetic monopoles. Within the material there exist magnetic "charges" and we suggest that a signature of this may be found by measuring the muon relaxation. Specifically it has been predicted that a high density of magnetic poles will be swept to the surface under applied field. Therefore we would like to measure the field lines emerging from the poles in a thin silver foil adjacent to the sample after a magnetic field has been pulsed on. Moreover once the magnetic field is pulsed off a measurable relaxation is expected. We have previously shown that this method of exterior muon implantation can assist interpreting conventional MuSR measurements as well as providing a useful contrast to bulk magnetization measurements.

Publications

Phys Rev Lett 99 (26) 267203 (2007)
Phys Rev B 75 220408 (2007)
Nature Physics 3 566 (2007)
Phys Rev B 72 224411 (2005)
Science 294 1495 (2004)

ISIS Sample record sheet

Principal contact	Professor S T Bramwell, s.t.bramwell@ucl.ac.uk, Tel: 020 7679 4648
Instrument	MUSR, 4 days, preferred contact is Giblin, S R (s.r.giblin@rl.ac.uk)
Special requirements	pulsed magnetic field 0-200G

SAMPLES

Material	Dy2Ti2O7
Formula	Dy2Ti2O7
Forms	Single crystal
Volume	-
Weight	1000 mg
Container / substrate	-
Storage requirements	-
Xtal details	

SAMPLE ENVIRONMENT

Equipment	T < 0.3K cryostat
Temperature range	50-5000 mK
Pressure range	-
Magnetic field range	-
Special equipment	pulsed magnetic field box required and coils

SAFETY

Hazards	-
Hazard details	-
Sample sensitivity	-
Experimental hazards	-
Sample prep hazards	-
Equipment hazards	-
Prep lab needed	No
Special equip reqs	-
Sample will be	Removed By User

1. Background

In spin ice materials like $Ho_2Ti_2O_7$ and $Dy_2Ti_2O_7$ [1] the Ising-like rare earth spins are analogous to hydrogen displacement vectors in water ice. Spin ice shares with water ice the Pauling "zero point" entropy and shows several interesting properties in applied magnetic field, including liquid-gas type transitions a so-called Kasteleyn transition and a giant entropy spike (see, for example [2]). Chemical modifications of spin ice include the "Berry phase" anomalous Hall effect material, $Nd_2Mo_2O_7$ [3], while an alternative approach to spin ice has utilised nanomagnetic arrays [4].

The latest twist in the story of spin ice is the recent discovery by Moessner, Castelnovo and Sondhi [5] that thermally induced defects in the spin ice state behave as unbound magnetic monopoles. These are an emergent material property (monopoles in the H-field) rather than elementary cosmic particles (monopoles in the B-field), but from a practical point of view they are expected to behave just like magnetic charges, confined in the material samples. The theory of effective H-monopoles is described in Jackson's textbook (*Classical Electrodynamics*): while there it is envisaged that these effective poles are essentially macroscopic objects, the difference in spin ice is that they are well defined almost down to the atomic scale. The magnetic scalar potential at a point **r** exterior to a sample containing such monopoles can be transformed, using Green's theorem to give the following relation:

$$\phi = \int \frac{\sigma dS}{r} + \int \frac{\rho dv}{r}$$

where σ is the surface pole density and ρ the bulk pole density, and the integral is over surface (S) and volume (v) respectively. This means that a muon implanted exterior to a sample of spin ice will sense a magnetic field distribution arising from the bulk as well as surface poles. In the zero field cooled phase of spin ice surface poles are completely absent (there is zero magnetization), but there is a thermal population of poles in the bulk, which must generate an exterior field distribution. As a field is applied these bulk poles will be swept to the surfaces, magnetizing the sample.

In recent work (*PRL*, accepted subject to minor amendments) we used exterior implantation to investigate a spin-ice related material, and demonstrated that a good signal could be obtained: the method avoids any problem of sample perturbation by the muons and muon relaxation by hyperfine effects, which is likely to be important in spin ice materials (all previous µSR on spin ice materials is extremely hard to interpret, probably for this reason). For our purposes, magnetic field detection by µSR is superior to a bulk method, as the slowly moving poles (estimated relaxation time 1 µs) are completely static on the timescale of bulk ac-susceptibility, but partly dynamic on the µSR time scale. Recent theoretical work (Holdsworth, submitted to *Nature Physics*) has demonstrated strong signatures of monopole diffusion in the dynamic response. Our plan is to do pulsed field µSR in red/green mode, which is magnetic pulse on, magnetic pulse off, thus giving a differential measurement. When the field is removed the monopoles on the surface (like surface charges) slowly diffuse into the bulk, which should roughly maintain the rms field at the muon site but introduce an observable dynamic component which can be compared with theory.

2. The Proposal

In the experiment we will implant muons into silver positioned near to a sample of spin ice, $Dy_2Ti_2O_7$ as in our recent work on $Tb_2Sn_2O_7$ (RB620576). To illustrate that we can measure external fields accurately we show in Fig. 1 the field derived from the precession frequency of muons implanted in silver at various distances from a magnetized block of nickel, versus the exact theoretical expression for the stray field distribution in the silver[6] (arising from the nickel: some parameters were adjusted within acceptable bounds to get the precise fit). It should be emphasised that spin ice is roughly as magnetically dense as nickel so when magnetised by a very weak field the response will be similar.

3. Experimental Details

We will use a single crystal in the temperature range 0.05 - 5 K and the field range 0 - 0.02 T (the field direction will be parallel to [110], an unimportant detail at these low fields where the susceptibility tensor is isotropic). We have already tested the dilution fridge with a pulsed transverse field of 0.02T to ensure that no significant heat load is induced on the fridge, the temperature was logged every 0.25s and no increase in temperature was observed.

We request 4 days of time on MuSR in order to accurately map out and optimise the response of the muons as a function of pulsed fields and temperature.

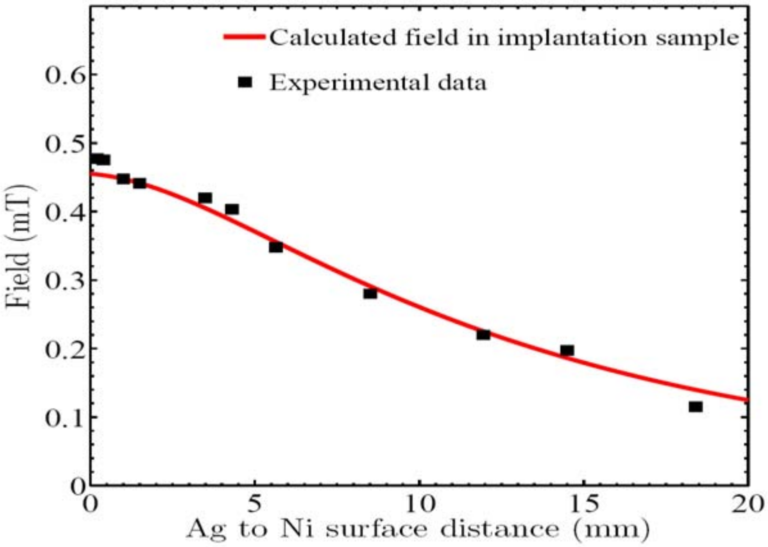

Fig. 1. With a magnetized piece of Nickel and muons implanted into a silver sample a known distance away from the Ni, the dipolar field can be calculated[6] and seen to match the experimental data.

[1] Bramwell and Gingras, *Science* **16**, 1495 (2001). [2] Moessner and Sondhi, *Phys. Rev. B* **68** 064411 (2003). [3] Taguchi et al., *Science* **291**, 2573 (2001). [4] Wang et al., *Nature*, **439**, 303 (2006). [5] Castelnovo *et al*., *Nature* (2008). [6] Engel-Herbert et al., *J. Appl. Phys*, **97**, 74504 (2005).