Magnetization of $Dy_2Ti_2O_7$

C.P. Aoyama, L. Yin, Y. Takano (UF, Physics); T. Sakakibara (Univ. Tokyo, ISSP); Q.J. Li, C. Fan, X.F. Sun (USTC, Physics)

Introduction

The pyrochlore titanate $Dy_2Ti_2O_7$ is a well-known spin ice [1], in which excitations analogous to magnetic monopoles exist — a phenomenon which has caused much excitement [2]. In a magnetic field applied along the [111] direction, the low-field spin-ice phase is immediately transformed to a kagome-ice phase, then to the so-called three-in one-out phase at about 0.9 T through a first-order transition. This sequence of transformations has been dramatically demonstrated by magnetization measurements at temperatures down to 0.35 K [3]. Very recently, an anomaly has been discovered at about 4.5 T in thermal-conductivity measurements performed at 0.36 K [4]. This unexpected finding has prompted us to revisit the magnetization of $Dy_2Ti_2O_7$ at the NHMFL DC-Field Facility by using a capacitive force magnetometer developed last year by three of us.

Experimental

The measurements were made on a 190 mg single-crystal sample of $Dy_2Ti_2O_7$ at 0.2 K in a superconducting magnet equipped with a dilution refrigerator. The magnetic field was applied parallel to the [111] axis, the direction for which the thermal-conductivity anomaly has been observed.

Because [111] is the direction along which the magnetization is the smallest at a given field, the sample has a strong tendency to tilt this axis away from the field direction. This means that the magnetic field will exert a large torque on the sample unless the field is perfectly parallel to the [111] direction. Against this torque, GE varnish was incapable of holding the sample on the magnetometer in a field up to 3.6 T. We had some success with Superglue, but even this adhesive failed after a few field sweeps up to 6 T.

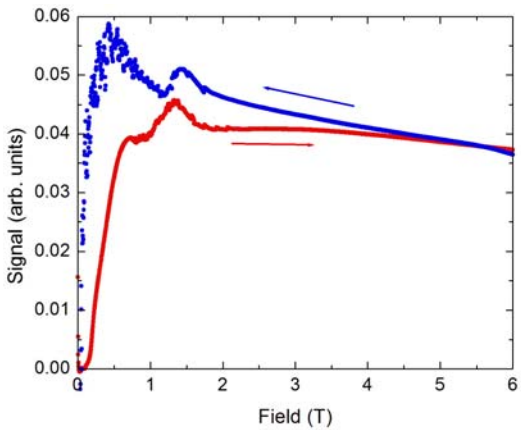

FIG 1. Magnetometer signal as a function of magnetic field at 0.2 K. The signal is a quantity that would be proportional to the magnetization, if a parasitic contribution due to magnetic torque were absent. The field was swept at the rates of 0.05 T/min and 0.01 T/min below and above 3 T, respectively.

Results and Discussion

A typical result obtained by using Superglue as a bonding agent is shown in Fig. 1. A step-like feature appears at about 1 T in the upward field sweep, indicative of the transition from the kagome-ice phase to the three-in one-out phase. But the signal decreases at slightly higher fields, and the downward-sweep signal is significantly different from the upward-sweep signal, suggesting that the sample was partly becoming detached from the magnetometer. Regardless, no anomaly was found above about 2.1 T, suggesting that the 4.5 T feature observed in thermal conductivity may be a subtle effect that does not involve a magnetic phase transition.

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