Field-Rotatable Calorimeter for NHMFL Top-Loading Portable Dilution Refrigerator

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Introduction

In quasi-low-dimensional systems, the existence of a particular physical state and the temperature and magnetic-field-dependence of its phase boundary often strongly depends on magnetic field orientation. To investigate these magnetic field orientation dependent phases, we have developed a rotatable sample-in-vacuum calorimeter [1] that can operate in a DC magnetic field of up to 45 tesla at temperatures between 0.1 K and 10 K. Samples are typically on the order of 1 mg in mass and can be up to 2 mm^2 × 0.5 mm in volume.

Experimental

The 0.300" diameter and 0.500" long cylindrical calorimeter is small enough to fit inside the top-loading single-axis rotator probe for the NHMFL DC field facility's portable dilution refrigerator (PDF); it can be rotated in field 360 degrees while the fridge remains at base temperature. The PDF is compatible with the DC field facility's 32 mm bore resistive and hybrid magnets, allowing measurements down to 0.1 K in fields up to 35 T and 45 T respectively. This is a significant advance over our previous 0.450" diameter calorimeter [2] designed for the 18 T dilution refrigerator/ superconducting magnet SCM1. Both calorimeters allow variation of sample temperatures between 0.1 K and 10 K.

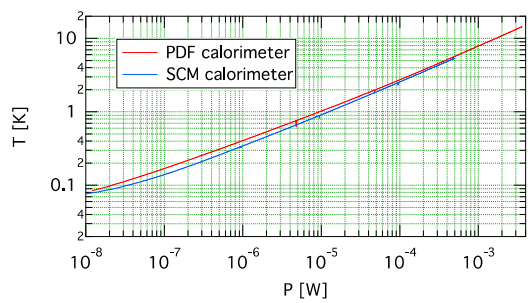

Fig. 1: temperature dependence of calorimeter internal platform temperature on platform heater power for the 45 T PDF and 18 T SCM1 rotatable calorimeters.

Initial testing and calibration of the calorimeter was done using the 18 T superconducting and 35 T resistive magnet systems at the DC field facility in Tallahassee FL and the following cryogenic systems: the SCM and PDF dilution refrigerators and a top-loading 3He system extended to include direct measurements of vapor pressure. Measurements at 45 T will be conducted in the future.

Results and Discussion

A comparative graph of platform temperature as a function of heater power for the two calorimeters is shown in Fig. 1. The cooling powers of the SCM1 and PDF dilution refrigerators are approximately 400 - 500 uW at 0.1 K, respectively, allowing for quick recovery of the fridge for calorimetric measurements between 0.1 K and 1 K; the upper limit of 10 K is set by the fridge maximum heat load of 4 mW.

As an initial test of the new calorimeter, we carried out measurements of the magnetic-field-angle dependence of magnetic-field-induced phases in the frustrated triangular-lattice S = 1/2 quantum Heisenberg antiferromagnet $Ba_3CoSb_2O_9$ using the PDF. Three magnetic phases are expected [3]: a low field 'Y' phase, an intermediate 'up - up - down' phase, and a high field 'V' phase. We find that the 'Y' and 'V' phases split into alternating and non-alternating co-planar sub-phases for H || a and that the field-induced phases for H || a and H || c are related to each other, as shown in Fig. 2.

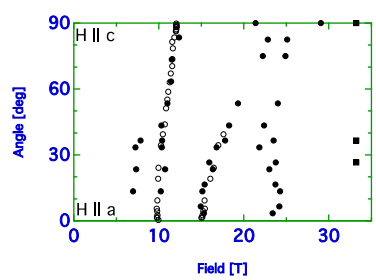

Fig.2: Magnetic-field-angle dependence of the field-induced phase transitions in the triangular quantum antiferromagnet $Ba_3CoSb_2O_9$

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References

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[3] Chubukov, A.V. *et al.*, Journal of Physics-Condensed Matter, **3**, 69-82 (1991).