Cascade of Magnetic-Field-Induced Quantum Phase Transitions in the $S=1/2$ Triangular-Lattice Antiferromagnet Cs$_2$CuBr$_4$

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Introduction

In a geometrically frustrated spin-1/2 Heisenberg antiferromagnet on a triangular lattice, spin-wave theory [1] predicts that the lifting of the classical degeneracy by quantum fluctuations will lead to the appearance of a collinear up-up-down phase at 1/3 of the saturation magnetization $M_s$, as observed in Cs$_2$CuBr$_4$ [2]. We have extended the high-magnetic-field phase diagram of this material to the saturation field $H_s=28.5$ T for fields directed along the crystallographic $c$ axis using the magnetocaloric effect as a probe, and in so doing, have discovered an unexpected series of additional gapped collinear spin states bounded by first order transitions at simple increasing fractions of the saturation magnetization.

Experimental

The experiment was performed in the 50-mm diameter bore, 31-tesla magnet at the NHMFL DC-Field Facility. A single-crystal sample of Cs$_2$CuBr$_4$ was placed in a miniature calorimeter [3] housed in a small plastic vacuum capsule which is top-loaded into the mixing chamber of a dilution refrigerator. To better detect the small-size features associated with some of the transitions, we minimized the addenda of the calorimeter by directly mounting the sample on a small 50 μm thin ruthenium-oxide thermometer and stabilized the temperature of the thermal reservoir (to which the sample-thermometer combination is weakly coupled) by continuously updating the setpoint of the temperature regulator as the magnetic field was varied.

Results and Discussion

The phase diagram constructed from this work (and our previous measurements below 18 tesla) is shown in the figure above. The antiferromagnetically ordered phases labeled 1/3, B, and 2/3 are believed to be commensurate and collinear; the phases labeled with Roman numerals I through V are either known to be or likely to be incommensurate. Magnetization data [4] suggests that the B and ‘2/3’ phases form magnetization plateaus at 5/9 and 2/3 of the saturation magnetization $M_s$. Supporting evidence for the commensurate nature of the very narrow B phase comes from NMR [5]. The A phase occurs where the magnetization is close to ½ of the saturation value $M_s$, although it does not form a magnetization plateau. Surprisingly, all three phases with magnetization plateaus — including the 1/3 phase — are bounded by first-order transition lines.

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References