Effect of site disorder on a spin-1/2 triangular-lattice antiferromagnet $Ba_3CoSb_2O_9$

by Qing Huang

Abstract

The novel up-up-down (UUD) ground state, which has been predicted to be stabilized by quantum fluctuations [1-3], is a good example of exotic magnetism in a triangular-lattice antiferromagnet (TAF). This quantum UUD state, that manifests itself with a constant magnetization (1/3 of the saturation magnetization) over a finite magnetic field range, has been reported in the S=1/2 TAF $Ba_3CoSb_2O_9$ [4-6]. We present a systematic study on the effect of quenched disorder on the single-crystalline form of $Ba_{2.8}Sr_{0.2}CoSb_2O_9$ using DC and AC susceptibilities and advanced neutron scattering. The DC susceptibility at zero field confirms an antiferromagnetic ordering below 2.8 K with an easy-plane anisotropy in $Ba_{2.8}Sr_{0.2}CoSb_2O_9$. The DC magnetization curve shows the UUD phase probably becomes weak after doping.

Introduction

In the two-dimensional (2D) triangular-lattice antiferromagnet (TAF), when the spin is small, especially S=1/2, strong quantum fluctuations in this magnet can lead to exotic quantum ground states. In recent years, research has been done on an effective spin-1/2 TAF $Ba_3CoSb_2O_9$. Here, the Co^{2+} ion has a Kramers doublet ground state due to the spin-orbit coupling, with an effective spin-1/2 moment [4,6]. This system orders below 3.8 K with a 120° spin structure [5]. However, its spin dynamics still retains various anomalous features. The high frequency excitation continuum has a large spectral weight, almost comparable to that of the single-magnon excitations. Furthermore, magnon spectral lines are broadened throughout the entire Brillouin zone. Neither feature can be explained by conventional spin wave theory [7], which indicates an intrinsic quantum origin. Meanwhile, a recent study shows the UUD state occurs in $Ba_3CoSb_2O_9$ with an $M_s/3$ magnetization plateau [4-6]. These experiments indicated that this system will show an exotic UUD phase under field. More studies on quantum magnets show that disorder in the sample, even on nonmagnetic sites, will affect the quantum fluctuations of the system. Especially for the compound $RbFe(MoO_4)_2$, the UUD is wiped out after K is doped on the Rb site [8]. It motivates us to induce the site disorder into $Ba_3CoSb_2O_9$ by doping Sr to Ba site and probe the influence on the UUD phase.

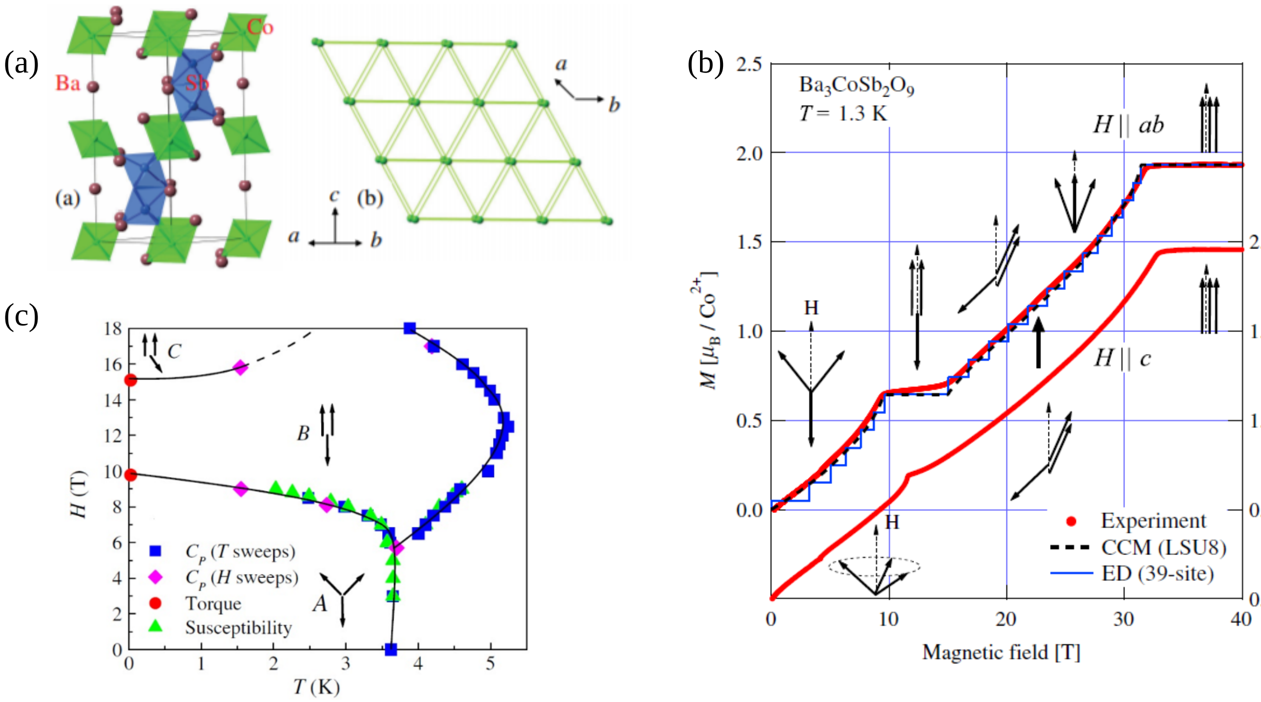

FIG.1. (a) Crystal structure of $Ba_3CoSb_2O_9$, with the space group P64/mmc. The Co atoms form an ideal triangular lattice [5]. (b) Magnetization curve of $Ba_3CoSb_2O_9$ at 1.3K. When magnetic field is applied in the ab plain, a plateau appears from 9T to 16T. The magnetic moment on the plateau is about $M_s/3$, which indicates the plateau represent an UUD phase [6]. (c) Magnetic phase diagram of Ba3CoSb2O9 for H//c. A, 120 structure phase; B, UUD phase; C, oblique phase. The arrows represent the spin structures in each phase [5].

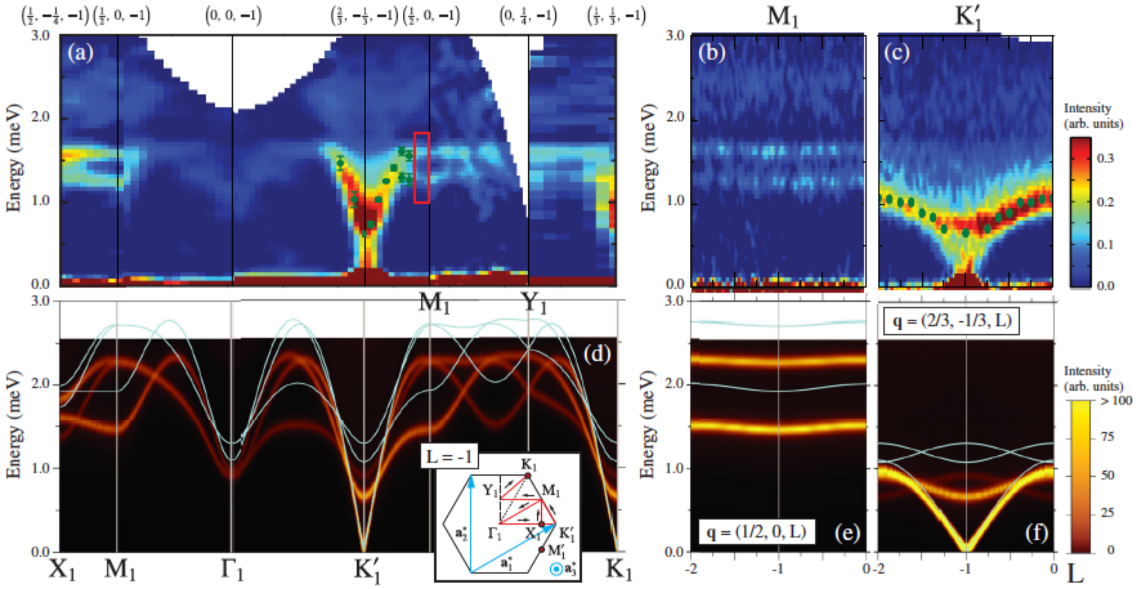

FIG. 2. INS spectra of Ba3CoSb2O9 as a function of the momentum and energy transfer at T=1.5K along the high symmetric (a) intralayer directions and the interlayer (b) [1/2, 0, L], and (c) [2/3, -1/3, L] directions in the reciprocal space. The background has been subtracted. The filled circles are peak positions from the measurements at the CG-4C TAS. The red rectangular frame in (a) represents the region where the decay effect is distinct and the details are discussed in Fig. 2(a). (d)–(f) The intensity plot of the dynamical structure factor along the same symmetry lines as in (a)–(c) for J=1.7 meV, J'/J=0.05, and Δ=0.89 at T=0K calculated with the non-linear spin-wave approximation. The energy resolution (0.063 meV) has been convoluted. The solid lines represent the poles in the Linear Spin Wave approximation [7].

Method

The single crystal sample of $Ba_{2.8}Sr_{0.2}CoSb_2O_9$ is grown with the traveling-solvent floating-zone technique. X-ray Laue diffraction was used to orient the crystal. DC susceptibility and magnetization were measured by a vibrating sample magnetometer.

Result and discussion

The susceptibility measurement under DC field shows that the transition temperature is around 2.9K in doped sample, which is lower than the transition temperature of pure compound, indicating that the spin fluctuation is stronger in the doped sample. The magnetization curves are measured up to 40T at NHMFL LANL. The plateau of doped compound seems to be weak in comparison with pure compound. And comparing the derivative curves of pure and doped compound, the peaks represent the beginning and end of plateau in doped compound is much weaker than the pure compound. So we can argue the UUD phase becomes weak or is likely to disappear after doping.

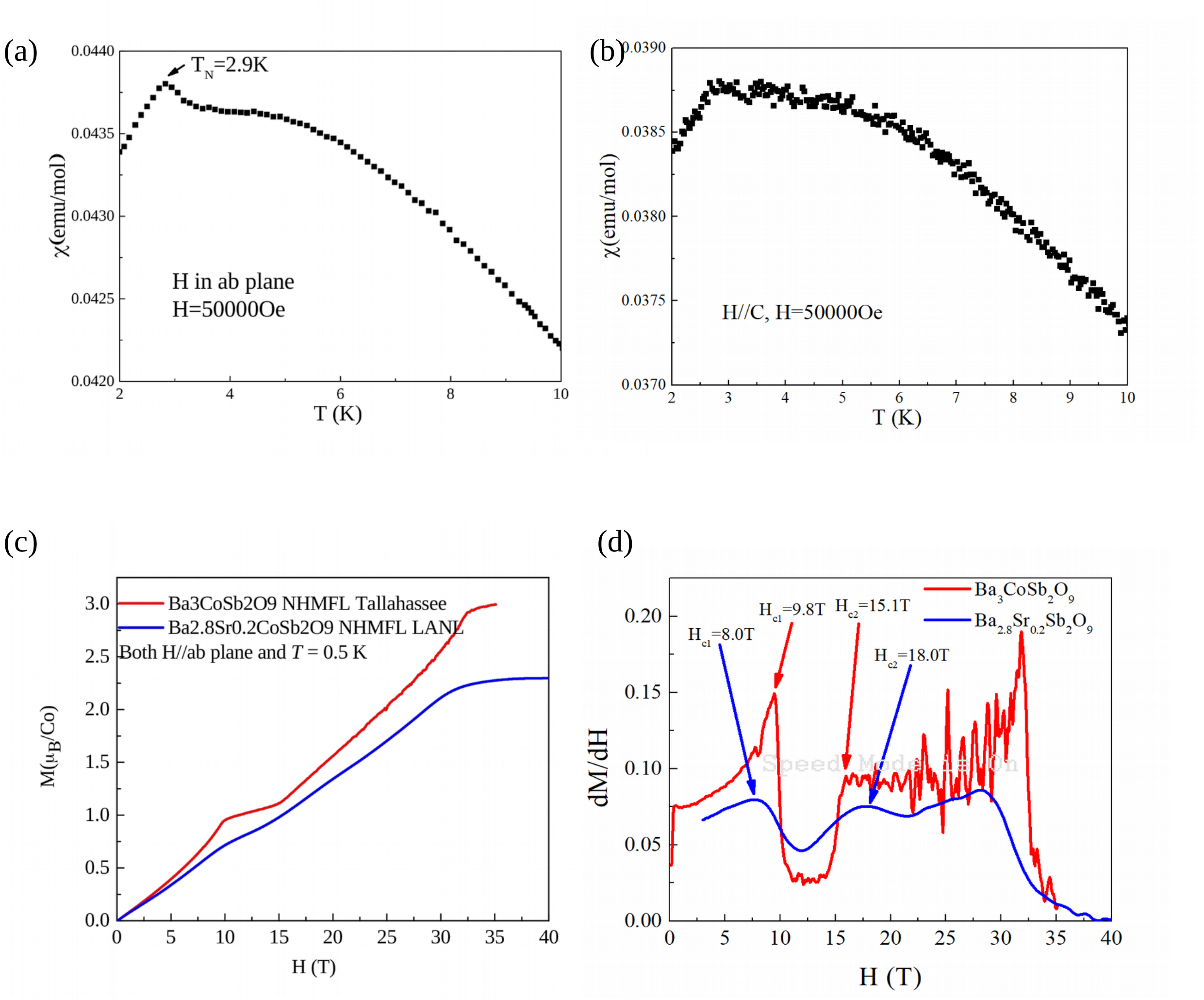

FIG.3. (a) χ-T curve measured under DC field in the magnetic field along ab plane. The transition temperature is around 2.9K for $Ba_{2.8}Sr_{0.2}CoSb_2O_9$. (b) χ-T curve measured under DC field in the magnetic field along c axis. Just a broad peak here. Such an anisotropy shows the ab plane is the magnetic easy plane. (c) Magnetization curve of doped compound and pure compound measured in DC field. The plateau of doped compound seems to be weak in comparison with pure compound. (d) Derivatives of the magnetization curves. The two peaks which represent the beginning and end of plateau become weak after doping.

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