μSR studies of two-dimensional antiferromagnets CaV_3O_7 and SrV_3O_7

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Abstract

A discontinuous change of muon-spin precession frequencies in CaV_3O_7 is observed at $T \sim 0.2$ K, indicating a possible spin reorientation. Our results suggest that CaV_3O_7 possesses the identical spin direction as isostructural SrV_3O_7 below ~ 0.2 K, although the spin directions in the two compounds are different at higher temperatures as determined by elastic neutron scattering.

Key words: antiferromagnet; vanadates; muon spin relaxation;

CaV_3O_7 contains a square lattice spin-1/2 Heisenberg system, in which 1/4 of the spin-1/2 vanadium lattice points are periodically depleted. It has been reported in neutron diffraction and susceptibility studies that CaV_3O_7 undergoes a phase transition at $T = 23$ K [1]. The magnetic structure of CaV_3O_7 is identified as so called a stripe phase, which consists of the chains of ferromagnetically aligned spins pointing along the c-axis with adjacent chains aligned antifferomagnetically [1]. Theoretical study [2] shows that the stripe phase is not stable in the framework of the classical theory, but is stabilized by quantum fluctuations when $J'/J > 0.69$, where J and J' denote the nearest and the next nearest neighbor interactions, respectively. In comparison with the theoretical and experimental results, the coupling constants are estimated as $J'/J \sim 1$. More detailed calculations for superexchange interactions have been performed using the local density approximation with the Coulomb potential correction of localized d electrons [3]. It has been found that the nearest-neighbor interaction has opposite signs and different magnitudes with directions, leading to the classical ground state of the stripe phase as observed experimentally [1].

Figure 1 shows the μSR spectra of polycrystalline CaV_3O_7. A clear muon precession is observed at low temperatures, indicating the magnetic long range order of the compound, with two frequencies forming a beat. The existence of two frequencies implies two magnetically inequivalent muon environments. A possible explanation for the existence of two frequencies is that muons stop at two different locations in a magnetic unit cell. The precession is suppressed around $T \sim 0.2$ K, and is recovered at higher temperatures. Moreover, a discontinuous change in the frequencies is clearly seen above and below ~ 0.2 K. As the temperature is further increased, the frequencies become smaller and vanishingly small at 23 K. The transition temperature is thus determined as 23 K, consistent with the previous susceptibility and elastic neutron scattering experiments

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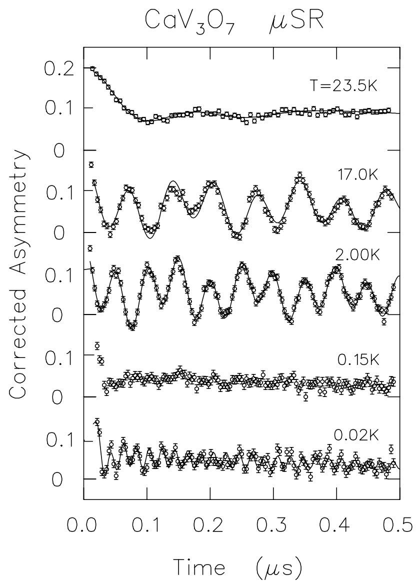

Fig. 1. μSR spectra in the polycrystalline specimen of CaV_3O_7 at several temperatures.

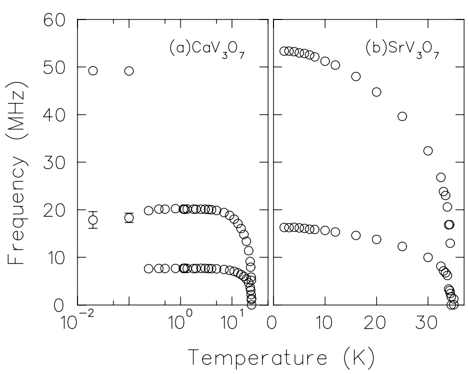

Fig. 2. Temperature dependences of the muon precession frequencies of polycrystalline CaV_3O_7 and SrV_3O_7.

[1].

Figure 2 shows the temperature dependence of the muon precession frequencies in CaV_3O_7 determined by fitting the μSR time spectra. The muon precession frequency is proportional to an internal magnetic field at the muon stopping sites, and thus is proportional to magnetization. Note again the discontinuous change in the frequencies at ~ 0.2 K. The continuous decrease of the frequencies towards 23 K indicates that the phase transition is a second order transition.

We now compare the results in CaV_3O_7 with those in isostructural SrV_3O_7 ($T_N = 35$ K). We find that two frequencies in CaV_3O_7 below ~ 0.2 K have almost the same value as those in SrV_3O_7 at 2 K (Fig. 2). We thus expect that CaV_3O_7 has the identical magnetic structure with SrV_3O_7 below ~ 0.2 K, and changes its magnetic structure above ~ 0.2 K. A recent neutron diffraction measurement determines that SrV_3O_7 has the stripe phase as well, but with spins pointing along the a-axis [5]. We therefore predict that in CaV_3O_7 the spins are oriented along the a-axis below ~ 0.2 K, and are reoriented into the c-axis above ~ 0.2 K.

The discontinuous change in the precession frequencies might as well imply the change of muon stopping sites, accompanied with muon diffusion. In fact, the suppression of the precession due to the muon diffusions is observed in the antiferromagnetic phase of $Ca_{0.86}Sr_{0.14}CuO_2$ ($T_N = 540$ K) above 300 K [4]. However, it is less probable that muon diffusion due to thermal excitations occurs at the temperature as low as 0.2 K. Furthermore, it is likely that at higher temperatures the muons continue diffusing and the precession is suppressed as in $Ca_{0.86}Sr_{0.14}CuO_2$, whereas the recovery of the precession is observed in CaV_3O_7. These considerations lead us to interpret that the frequency jump in CaV_3O_7 at ~ 0.2 K is due to spin reorientation.

Similar discontinuities in magnetization have already been reported for several ferromagnets like FeS [6] and $CuCl_2{\cdot}2H_2O$ [7], and have been ascribed to an anisotropy in exhange interactions due to LS couplings [8,9]. The discontinuous change of the muon-spin precession frequencies in CaV_3O_7 might indicate that anistropic superexhange interactions possibly exists as well.

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