MAGNETIC FIELD EFFECTS ON THE ONE-DIMENSIONAL $\boldsymbol{S = 1/2}$ ANTIFERROMAGNET Yb_4As_3*

M. Kohgi, K. Iwasa

Department of Physics, Tokyo Metropolitan University, Tokyo 192-0397, Japan

J.-M. Mignot

Laboratoire Léon Brillouin, CEA/Saclay, 91191 Gif sur Yvette, France

A. Hiess

Institut Laue-Langevin, BP156, F-38042 Grenoble, France

A. Ochiai

Center for Low Temperature Science, Tohoku University, Sendai 980-8578, Japan

and H. Aoki

Institute for Solid State Physics, University of Tokyo, Kashiwa 227-8581, Japan

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Inelastic neutron scattering experiments under magnetic field were performed on the one-dimensional quantum antiferromagnet Yb_4As_3. When a magnetic field is applied perpendicular to the Yb^{3+} chain, the material exhibits a gap-opening phenomenon due to the induced staggered field originated from the Dzyaloshinsky–Moriya interaction. It was confirmed that the spectrum remains gapless when a magnetic field is applied parallel to the Yb^{3+} chain. However, the gapless mode at the incommensurate wave vector which is predicted by the theories was not found.

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Yb_4As_3 is a unique lanthanide compound which exhibits low-dimensional quantum spin phenomena. It has an anti-Th_3P_4 type cubic crystal structure at high temperatures and undergoes a charge order transition at 290 K, giving well separated one-dimensional chains of Yb^{3+} ion along the [111] direction [1]. Inelastic neutron scattering experiments on a single crystal sample of Yb_4As_3 [2] revealed that the Yb^{3+} chains exhibit low energy magnetic excitations which are well characterized as those of a one-dimensional (1D) spin 1/2 Heisenberg system with a nearest neighbor antiferromagnetic coupling (1D-HAF) with $J = 2.2$ meV. Shiba *et al.* showed that the effective Hamiltonian for the ground state doublet of this system is well expressed by the 1D-HAF model together with Dzyaloshinsky–Moriya (D–M) interaction due to no inversion symmetry in the Yb^{3+} chain [3]. On the other hand, the specific heat measurement under magnetic fields indicated the opening of a gap in the energy spectrum of the system [4]. We performed further measurements of spin dynamics of Yb_4As_3 under magnetic field, and found that the spectrum at the 1D wave vector around $q = 1$ $[\pi/d]$ (d: atomic distance in the 1D chain) shows an energy gap which is proportional to $H^{2/3}$ [5]. The result strongly supports the theory presented by Oshikawa *et al.* [6] who explained the gap opening phenomenon by the induced staggered field due to the D–M interaction on the basis of the conformal field theory.

Since the D–M interaction works only between spin components perpendicular to the chain, it is naturally considered that a magnetic field applied parallel to the Yb^{3+} chain ($H \parallel \langle 111 \rangle$) does not cause any other effect than the simple Zeeman effect and the spin system of Yb_4As_3 will behave as a simple 1D-HAF system under magnetic field. To check this point, we have performed an inelastic neutron scattering experiment on this material.

The inelastic neutron scattering experiment was performed on the cold neutron triple axis spectrometers IN14 at ILL, Grenoble, France. A single crystal sample ($\sim 8 \times 8 \times 4$ mm^3) with the [1 -1 0] axis vertical was set in a superconducting magnet which produces a horizontal magnetic field at the sample position. The magnetic field was applied parallel to the [111] direction along which the chains of Yb^{3+} ions are formed in the trigonal phase. The strain-cool technique was applied to make a single domain sample [1,2].

Fig. 1 depicts the 1D wave vector dependence of the response with constant energy-transfer of $\hbar\omega$=0.2 meV ($\sim J/10$) around q=1 measured at 1.5 K with and without magnetic field.

The spectrum at H=0 just corresponds to the constant energy cut of the des Cloiseaux–Pearson spin wave mode with two spinon continuum. The slight shift of the spectra to smaller q side is due to the resolution effect of the spectrometer. The spectrum at H=3.8 T does not show any essential difference from that of zero field except for a slight decrease of intensity around q=1. This is a quite unexpected result since the component of the

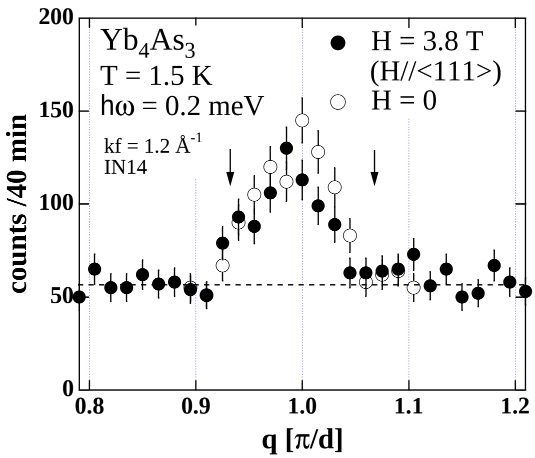

Fig. 1. Magnetic field dependence of the constant-energy response ($\hbar\omega$=0.2 meV) across the q=1 1D ridge at 1.5 K.

spin correlation function parallel to the direction of the magnetic field is expected to have a gapless mode at $q=1\pm\delta$ when a magnetic field is applied to a 1D-HAF system [7]. The δ value for Yb_4As_3 in the present experimental condition can be calculated by using the g factor parallel to the Yb^{3+} chain ($g_{\|}$=2.9) determined by our neutron scattering experiments [8]. The expected positions of the incommensurate mode for Yb_4As_3 are shown by arrows in Fig. 1. Since both parallel and perpendicular components of the spin correlation function appear with comparable weight in the scattering cross section at the scattering vectors where the measurements were done, Q ~(1.1, 1.1, -0.2), new peaks should be observed around the arrow positions when the field is applied. However, there is no sign of such peaks. This is clearly incompatible with the 1D-HAF theory. Similar results were also observed for the scans with $\hbar\omega$=0.4 and 0.6 meV in the same q region.

Fig. 2 depicts the constant-Q scans at q=0.6 at 1.5 K with and without magnetic field. The features of the change of the spectrum are rather similar to the case of the typical quasi-1D system such as Cs_2CuCl_4 [9] and are not inconsistent with the theoretical prediction for the 1D-HAF model [7]. This result is in contrast to the result at the low energy excitation region around q=1 where a clear disagreement with the theory is seen.

The observed features of the low energy spin excitations of Yb_4As_3 under magnetic field parallel to the Yb^{3+} chain are rather favorable to the explanation by the spin wave theory with dipole interaction [10] than to that by the direct treatment of the quantum spins of the 1D-HAF system with Zeeman effect [7]. However, the situation is reversed for the response at higher excitation energies as shown in Fig. 2. This fact indicates that there is a possibility of the existence of another unknown interaction in Yb_4As_3.

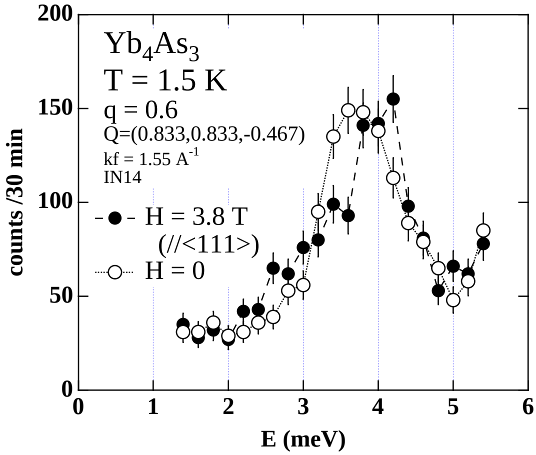

Fig. 2. Magnetic field dependence of the constant-Q response at q=0.6 at 1.5 K.

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