J-PARC MLF Experimental Report	提出日 Date of Report May 1, 2013
課題番号 Project No. 2013A0008 実験課題名 Title of experiment Investigation into origin of magnetic order in spin-cluster systems 実験責任者名 Name of principal investigator Masashi Hase 所属 Affiliation National Institute for Materials Science	装置責任者 Name of responsible person Kenji Nakajima 装置名 Name of Instrument/（BL No.） BL14, AMATERAS 実施日 Date of Experiment Apr. 1 to 5, 2013

試料、実験方法、利用の結果得られた主なデータ、考察、結論等を、記述して下さい。（適宜、図表添付のこと）
Please report your samples, experimental method and results, discussion and conclusions. Please add figures and tables for better explanation.

1. 試料 Name of sample(s) and chemical formula, or compositions including physical form.

We used about 9 g $Cu_2{}^{114}Cd^{11}B_2O_6$ (copper cadmium pyroborate oxide) powders for inelastic neutron scattering experiments performed on the AMATERAS spectrometer at BL14.

2. 実験方法及び結果（実験がうまくいかなかった場合、その理由を記述してください。）
Experimental method and results. If you failed to conduct experiment as planned, please describe reasons.

From magnetization results and magnetic structure determined using neutron diffraction, we determined that the spin system in $Cu_2CdB_2O_6$ consists of spin-1/2 tetramers (4-spin clusters). The Hamiltonian is $J_1S_2*S_3+J_2(S_1*S_2+S_3*S_4)$ with J_1 = 264 K (AF) and J_2 = -143 K (ferromagnetic). In the spin tetramer with these J values, the ground state (GS) is spin singlet (S^T = 0). However, $Cu_2CdB_2O_6$ shows antiferromagnetic (AF) long-range order (AFLRO) below T_N = 9.8 K. The energy difference between the ground state and the first excited spin-triplet (S^T = 1) state (1ES) is small (16.6 K = 1.43 meV). The other higher excited states are separated enough in energy (227 K = 19.6 meV or more). We infer that “magnetic” ground state in $Cu_2CdB_2O_6$ is formed by mixing of the ground and first excited states of the spin tetramer because of inter-tetramer interactions. Therefore, AFLRO is possible in the magnetic ground state with help of the inter-tetramer interactions.
In order to understand the origin of AFLRO in $Cu_2CdB_2O_6$, it is important to investigate low-lying magnetic excitations with typical energy transfer 1 meV. Therefore, we performed inelastic neutron scattering (INS) experiments on $Cu_2{}^{114}Cd^{11}B_2O_6$ powders using the AMATERAS spectrometer installed at BL 14.

2. 実験方法及び結果（つづき） Experimental method and results (continued)

Figure 1 shows Q-ω-intensity maps at 5.0 K in the ordered state and at 9.9 K ~ T_N. In the data at 5.0 K (left figure), magnetic excitations are apparent between 2.0 and 2.7 meV in the small Q range. The INS intensity has maxima around ω = 2.4 meV and Q = 0.5 Å^{-1}. We consider that the origin of the magnetic excitations is the excitation from GS to 1ES. A dispersion from ω = 0 meV and Q ~ 0.7 Å^{-1} seems to exist. On heating the magnetic excitations shift to lower ω and become broader. The INS intensity at 9.9 K (right figure) has maxima around ω = 1.8 meV and Q = 0.5 Å^{-1}. The dispersion from ω = 0 meV and Q ~ 0.7 Å^{-1} is apparent. Each tetramer is affected by staggered and random fields generated by neighboring tetramers in the ordered state and the paramagnetic state, respectively. The broadening may be caused by the random fields. We will analyze quantitatively obtained data.

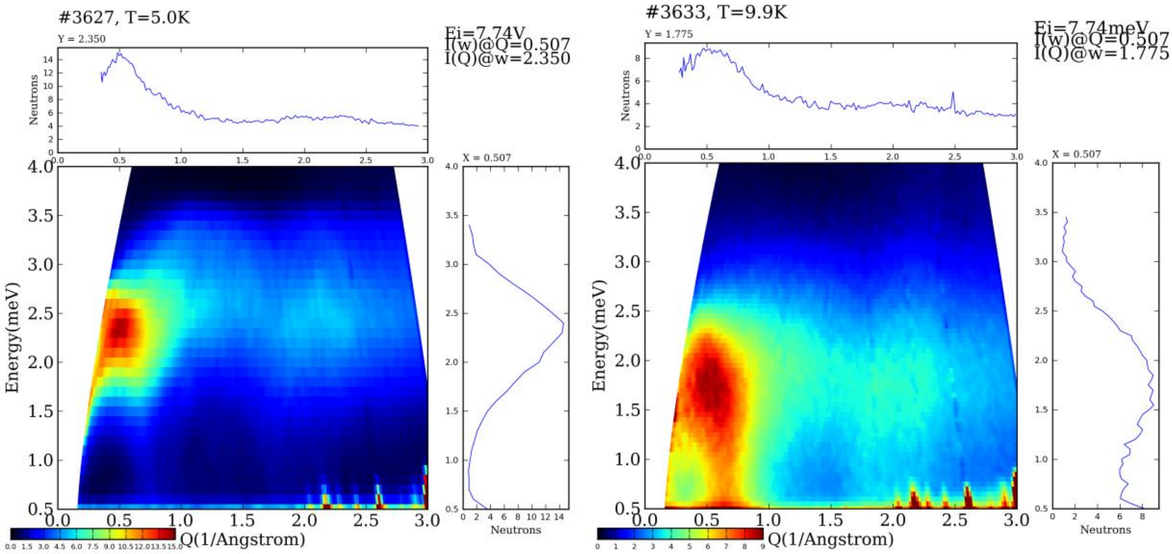

Fig. 1 Q-ω-intensity maps at 5.0 K (left) and 9.9 K (right). The incident neutron energy is 7.74 meV.