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## NMR STUDY OF $R_6Mn_{23}$ COMPOUNDS

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**Abstract.** - The  $^{55}\text{Mn}$  NMR spectra have been observed under zero and external field up to 50 kOe. The negative field dependence of the resonance frequency is obtained for all compounds and explained by the weak anisotropy. The transferred hyperfine fields in  $\text{Dy}_6\text{Mn}_{23}$  and  $\text{Ho}_6\text{Mn}_{23}$  are small in magnitude and comparable with those of  $\text{Y}_6\text{Mn}_{23}$ .

The compounds  $R_6\text{Mn}_{23}$  have a cubic  $\text{Th}_6\text{Mn}_{23}$ -type structure which is most stable in the intermetallic compounds between rare-earth (R) and Mn atoms ( $\text{RMn}_2$ ,  $R_6\text{Mn}_{23}$  and  $\text{RMn}_{12}$ ). There are crystallographically four inequivalent Mn sites (4b, 24d, 32f<sub>1</sub> and 32f<sub>2</sub>) with a population ratio of 1;6;8;8. The high magnetic ordering temperatures of  $R_6\text{Mn}_{23}$  indicate the strong coupling between the magnetic moments, while the Mn moments are estimated to be very small ( $0.4 \mu_B/\text{Mn}$ ) by the magnetic measurements. The R and Mn moments are antiparallel to each other except in  $\text{Gd}_6\text{Mn}_{23}$  [1]. Delapalme *et al.* [2] investigated the ferrimagnetic arrangement of Mn moments in  $\text{Y}_6\text{Mn}_{23}$  by the polarized neutron experiments. They estimated the Mn moments to be  $-2.81 \mu_B$  (4b),  $-2.0 \mu_B$  (24d),  $1.79 \mu_B$  (32f<sub>1</sub>) and  $1.77 \mu_B$  (32f<sub>2</sub>) at 4.2 K.

The NMR method is useful for the microscopical investigation of the magnetic properties of these compounds. In this paper we report the  $^{55}\text{Mn}$  NMR of  $R_6\text{Mn}_{23}$  (R = Gd, Dy and Ho) and discuss the hyperfine fields of these compounds.

The samples were prepared by melting the constituent elements of 99.9 % in purity in an induction furnace under a purified argon atmosphere. A small amount of excess Mn metal was added to avoid weight loss due to evaporation. The X-ray diffraction shows the single phase of  $\text{Th}_6\text{Mn}_{23}$ -type structure after annealing at 900 °C for a few days.

Figure 1 shows the typical  $^{55}\text{Mn}$  NMR spectra of  $R_6\text{Mn}_{23}$  (R = Gd and Ho) at 4.2 K under zero field. These spectra are mainly due to the nuclei located in domain walls. The field dependences of the  $^{55}\text{Mn}$  NMR spectra are plotted in figure 2 where the lines indicate the  $^{55}\text{Mn}$  resonances as a function of the external field with the slope of  $-^{55}\gamma$  ( $= 1.05 \text{ kHz/Oe}$ , nuclear gyromagnetic ratio).

There exist mainly three peaks in each  $^{55}\text{Mn}$  spectra due to the nuclei located in magnetic domains and assigned to the different crystallographic sites. They are denoted as A, B and C. Since the intensity of the lowest frequency peak (C) is much stronger than the others, it may be attributed to 32f<sub>1</sub> and 32f<sub>2</sub> sites whose moments are almost the same [3, 4]. The peaks

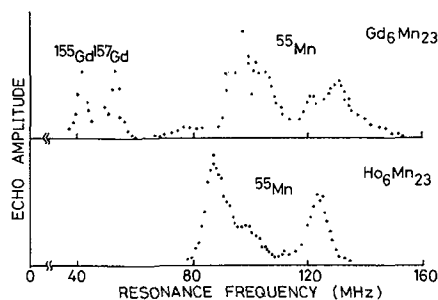


Fig. 1. -  $^{55}\text{Mn}$ ,  $^{155}\text{Gd}$  and  $^{157}\text{Gd}$  NMR spectra by the spin-echo method under zero field at 4.2 K. The signals are attributable to the nuclei in domain walls.

A and B may be due to 4b and 24d sites, respectively, on the consideration of their Mn moments. These site assignments are consistent with those of  $\text{Y}_6\text{Mn}_{23}$  by Yoshimura *et al.* [4].

Since the magnetic moments of R atoms couple antiferromagnetically with Mn moments and the magnetic moment of R-sublattice is larger than that of Mn-sublattice, the field dependence of the  $^{55}\text{Mn}$  resonance frequency is expected to be in up slope ( $+^{55}\gamma$ ) by assuming the hyperfine field at  $^{55}\text{Mn}$  nucleus to be negative in sign. It is surprising that the field dependence of the  $^{55}\text{Mn}$  resonance frequency is in down slope ( $-^{55}\gamma$ ) as shown in figure 2. The negative field dependence may be due to the weak anisotropy in these compounds and ferrimagnetism is easily broken by applying an external field like in  $\text{Y}_6\text{Mn}_{23}$  [3, 4]. The  $^{55}\text{Mn}$  NMR spectra under zero field are extremely enhanced by domain wall motions. Then we estimate the values of the hyperfine fields by extrapolating to  $H = 0$  in the field dependence of the resonance frequency and the values are listed in table I (in kOe).

The transferred hyperfine fields ( $H_t^R$ ) from Dy and Ho are very small for the signals A and C, because the hyperfine fields are almost the same with those of  $\text{Y}_6\text{Mn}_{23}$ . For the signal B the  $H_t^R$  is proportional to  $-3.1(g-1)J[\text{kOe}]$  for R = Gd, Dy and Ho. In the case of  $\text{Gd}_6\text{Mn}_{23}$ , the hyperfine fields of signals

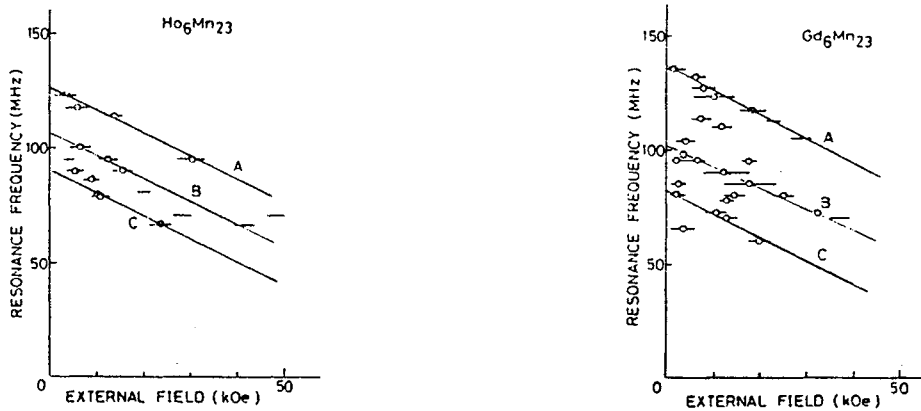


Fig. 2. - The field dependence of  $^{55}\text{Mn}$  resonance frequency in  $\text{Gd}_6\text{Mn}_{23}$  and  $\text{Ho}_6\text{Mn}_{23}$  at 4.2 K. The solid and dotted lines are plotted with the slope of  $-^{55}\gamma$  values. The lines A, B and C denote the main peaks of signals.

Table I. - The  $^{55}\text{Mn}$  hyperfine fields in  $\text{R}_6\text{Mn}_{23}$  (kOe).

Signal	Site	$\text{Gd}_6\text{Mn}_{23}$	$\text{Dy}_6\text{Mn}_{23}$	$\text{Ho}_6\text{Mn}_{23}$	$(\text{Y}_6\text{Mn}_{23})$
A	4b	-131	-122	-122	-122
B	24d	-98	-99	-101	-109
C	$32f_1$	-79	-86	-86	-88
	$32f_2$				

The data of  $\text{Y}_6\text{Mn}_{23}$  are taken from reference [4].

A and C largely deviate from those of  $\text{Dy}_6\text{Mn}_{23}$  and  $\text{Ho}_6\text{Mn}_{23}$ . Other signals than signals A, B and C were observed as shown in figure 2. These anomalous phe-

nomena are originated from the complex magnetic structure of  $\text{Gd}_6\text{Mn}_{23}$ .

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