ON THE MAGNETIC PROPERTIES OF Mn_5Ge_3

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(Recieved May 1, 1967)

§ 1. Introduction

It has been reported[1] that the compound Mn_5Ge_3, which has a crystal structure of $D8_8$ type, is ferromagnetic with Curie point of 304°K and an easy direction of magnetization along the c-axis.

In the previous paper[2], the magnetocrystlline anisotropy energy of a single crystal of Mn_5Ge_3 was determined by means of both magnetotorque and magnetization curve methods in the temperature range from 77°K to 290°K. The temperature dependence of the magnetocrystalline anisotropy energy was discussed in the same paper on the basis of the magnetic dipole-dipole interaction, but it could not explained sufficiently by this origin.

Recentry, one of the authors has investigated the temperature dependence of the uniaxial type magnetic anisotropy constant K_1 for the ferromagnetic compound Fe_5Ge_3 basing on a one ion model with the molecular field approximation[3].

In this paper, we have presented more detailed studies on the temperature dependence of the anisotropy energy of the compound Mn_5Ge_3. The anisotropy energy was measured down to the liquid helium temperature in high magnetic field and a similar calculation to ref. 3 was carried out.

§ 2. Experimental results and discussion

The magnetocrystalline anisotropy energy of the compound Mn_5Ge_3 is determined from measurements of the magnetization curve[4]. Fig. 1 shows the curves of magnetization at 1.2°K along the a- and the c-axis.

Using the usual expression of uniaxial anisotropy energy, $E=K_1 \sin^2\theta$, the K_1 is obtained to be 4.4×10^6 erg/cc at 1.21°K and 4.3×10^6 erg/cc at 77°K respectivelly. Assuming that the uniaxial anisotropy energy of the Mn_5Ge_3 is composed of two parts, it is given by

$$K_1=K_{\text{dip}}+K_{\text{one ion}}, \tag{1}$$

where the first term is one due to the dipole-dipole interaction energy[2] and the second is that originated from the one ion model. Then, let us consider the second term in Eq. (1).

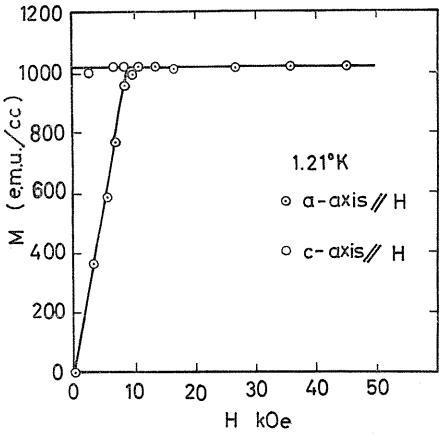

FIG. 1. Magnetization curves of Mn_5Ge_3.

We assume that the uniaxial anisotropy energy of single ion is given as follows[3)5)6)],

$$K = -\sum_j N_j D_j S_{zj}^2, \tag{2}$$

where j are the indeces for A and B sublattice. Then the temperature dependence of the K is given by

$$\begin{aligned} K_{\text{one ion}} &= \sum_j N_j D_j \langle S_j^2 \rangle_j, \\ \langle S_z^2 \rangle_j &= \frac{1}{2}\{3 m_{zj}^2 - S_j(S_j+1)\}, \\ m_{zj}^2 &= \sum_{ms_j=-s_j}^{s_j} m_{s_j}^2 \exp(m_{s_j} g_j \mu_B H_{ej}/kT) \Big/ \sum_{ms_j=-s_j}^{s_j} \exp(m_{s_j} g_j \mu_B H_{ej}/kT) \end{aligned} \tag{3}$$

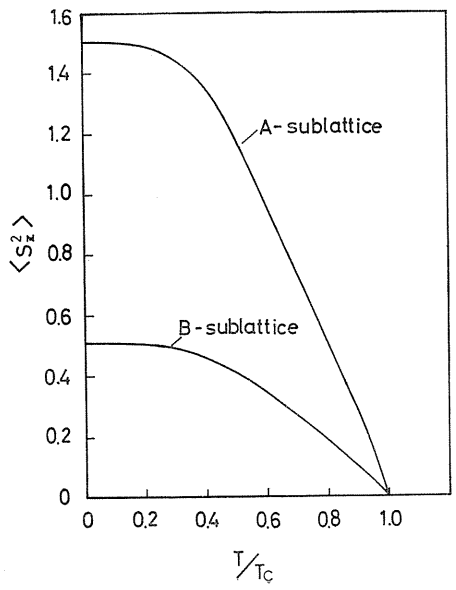

FIG. 2. Temperature dependence of $\langle S_z^2 \rangle$ assuming $S_A = 3/2$ and $S_B = 1$.

where N_j is the number of contributing ions on sublattice j per unit volume, D_j is the anisotropy constant per ion, g_j is the g-factor (assumed as $g_j=2$), H_{ej} is the exchange field, and S_j is the spin quantum member.

Now, following the spin values $S_A = 3/2$ on the 2(a) site and $S_B = 1$ on the 2(d) according to Katsuragi's[7] and Kanematsu's[1] models for the ferromagnetic compound Mn_5Ge_3, we introduce the two independent parameters D_A and D_B, because both S_A and S_B contribute to the anisotropy energy.

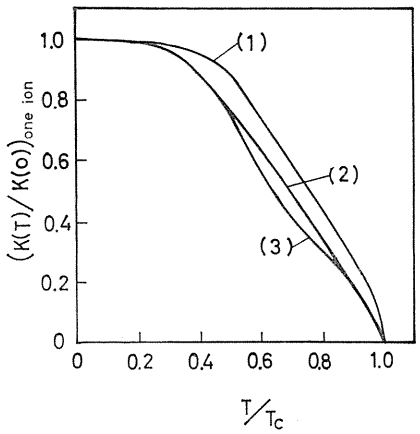

FIG. 3. Uniaxial anisotropy energy vs temperature curves for the various D-values.

(1) $D_A=-1$ $D_B=5$
(2) $D_A=0.6$ $D_B=0.2$
(3) $D_A=0.8$ $D_B=-0.4$

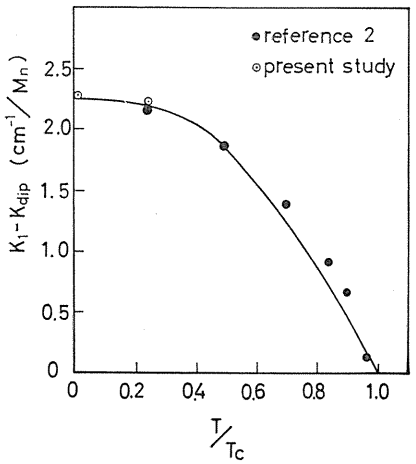

FIG. 4. Experimental result is compared with the calculated curve. K_{dip}: Calculated anisotropy for the dipole-dipole interaction energy[2].

$K_1=K_{\text{one ion}}+K_{dip}$

The S_{zj}^2 as a function of the temperature was calculated from the Eq. (3). The results are shown in Fig. 2.

Futher, the calculated curves of the uniaxial anisotropy energy for the various D-values is given in Fig. 3.

On the basis of experimental results, the fittest value for D_A and D_B can be obtained as 0.70 cm^{-1} and 2.6 cm^{-1} per ion respectively and the curve is shown in Fig. 4.

The agreement seems satisfactory except for the higher temperature region which is strongly influenced by the thermal expansion. We can conclude that the temperature dependence of the uniaxial anisotropy for Mn_5Ge_3 is well interpreted by a one ion approximation on the basis of Katsuragi's and Kanematsu's spin schemes, rather than Forsyth's one which has the spin values $S_A=1$ and $S_B=3/2$.

3. Conclusion

The uniaxial magnetic anisotropy constants of Mn_5Ge_3 are determined from magnetization measurements as 4.4×10^6 erg/cc at 1.2°K and 4.3×10^6 erg/cc at 77°K. The temperature dependence of the uniaxial anisotropy energy is discussed using a molecular field approximation by a one ion anisotropy model on Katuragi's and Kanematsu's spin schemes.

Acknowledgements

The authors wish to express their hearty thanks to Prof. T. Hirone for his kind advice in the projection of the pressent work,

Reference

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