EFFECTIVE EXCHANGE FIELDS IN SUBSTITUTED GADOLINIUM FERRITE GARNETS

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The rare earth ferrite garnets $\{R_3\}[Fe_2](Fe_3)O_{12}$ are ferrimagnets having three nonequivalent magnetic sublattices, *a*, d, and c. The magnetic moments of the ions in each sublattice are subjected to an effective exchange field produced by both the magnetic moments of the ions of the given sublattice and the magnetic moments of the ions of the two other sublattices.

Let us consider ions in the rare earth c sublattice. Since the exchange interaction between rare earth ions in the garnet structure is much weaker than the exchange interaction between rare earth and iron ions, the H_{ext} which acts on the rare earth ions results primarily from the iron ions in sublattices *a* and d [1]. It seemed worthwhile to determine whether this assumption is valid for the substituted rare earth ferrite garnets.

We studied gadolinium ferrite garnets in which the iron was substituted by nonmagnetic ions in both the *a* and d sublattices:

$$\{Gd_{3-x_0}Ca_{x_0}\}[Fe_{2-x_0}Sn_{x_0}](Fe_3)O_{12};$$
$$\{Gd_{3-x_T}Ca_{x_T}\}[Fe_2](Fe_{3-x_T}Si_{x_T})O_{12}.$$

A distinctive feature of these systems is that as x_0 (the concentration of nonmagnetic ions in the octahedral sublattice) increases, the magnetic moment of the d sublattice remains unchanged (the magnetic moment of the over-all iron sublattice increases), while as x_T (the concentration of nonmagnetic ions in the tetrahedral sublattice) increases, the magnetic moment of the d sublattice decreases (as does the magnetic moment of the over-all iron sublattice with $x_T<1$).

In an effort to determine how changes in the magnetic moments of the *a* and d sublattices would affect the H_{exc} acting on the rare earth ions, we studied the following substituted gadolinium ferrite garnets: $x_0=0{,}0;\ 0{,}3;\ 0{,}6;\ 0{,}9$ and $x_T=0{,}3;\ 0{,}6;\ 0{,}9;\ 1{,}2$. The procedure used to synthesize the samples, the lattice constants, and the method used to measure the magnetization were reported in [2].

To determine H_{exc} we used an equation from molecular field theory for the temperature dependence of the spontaneous magnetization of a rare earth sublattice:

$$M_{SR}=M_{RO}B_S\left(\frac{2S\mu_0 H_{exc}}{kT}\right).$$

We find the temperature dependence of the spontaneous magnetization of the rare earth sublattice by finding the difference between the temperature dependences of the spontaneous magnetization of gadolinium ferrite garnet and yttrium ferrite garnet; the temperature dependence of the spontaneous magnetization of the latter was identified as the temperature dependence of the spontaneous magnetization of the *a* and d iron sublattices together. For this purpose we first recorded the spontaneous magnetization of the substituted gadolinium ferrite garnets and the substituted yttrium ferrite garnets of analogous composition. The magnetization was measured at temperatures from that of liquid nitrogen to the Curie point.

Figure 1 shows $H_{exc}(T)$ curves for the gadolinium ferrite garnets for those concentrations of the nonmagnetic ions in the d sublattice. We see that H_{exc} decreases with increasing temperature and with increasing concentration of the nonmagnetic ions in the d sublattice.

Similar temperature and composition dependences were observed for H_{exc} in the system of gadolinium ferrite garnets with substitution in the *a* sublattice.

Extrapolating the $H_{exc}(T)$ curves to $T=0°K$, we found the $H_{exc}(x)$ dependence shown in

Fig. 2. We see from Fig. 2 that H_{exc} decreases as nonmagnetic ions are added to either the *a* or d sublattice. The weak temperature dependence of H_{exc} at low temperatures, found for all the garnets studied with substitution in either the *a* or d sublattice, is noteworthy.

The value of H_{exc} acting on the rare earth ions in the ferrite garnets can be written as

$$H_{exc} = \gamma M_{SR} + \lambda M_{Fe},$$

where γ and λ are the exchange-interaction parameters for the interactions of rare earth ions and for rare earth ions with iron ions, respectively.

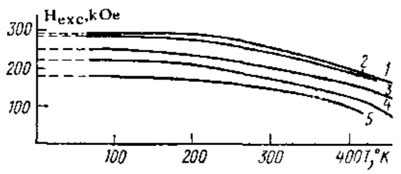

Fig. 1. Temperature dependences of the exchange fields acting on the gadolinium ions in the $\{Ga_{3-x}Ca_x\}$ $[Fe_2]$ $(Fe_{3-x}Si_x))O_{12}$ ferrite garnets. 1) $x = 0$; 2) $x = 0{,}3$; 3) $x = 0{,}6$; 4) $x = 0{,}9$; 5) $x = 1{,}2$.

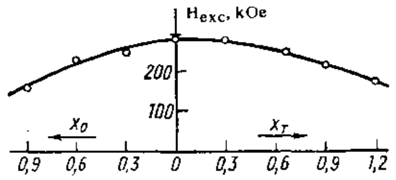

Fig. 2. Composition dependence of the exchange field acting on the gadolinium ions at 0°K in the $\{Ga_{3-x_T}Ca_{x_T}\}[Fe_2](Fe_{3-x_T})O_{12}$ and $\{Ga_{3-x_0}Ca_{x_0}\}[Fe_{2-x_0}Sn_{x_0}](Fe_3)O_{12}$ ferrite garnets.

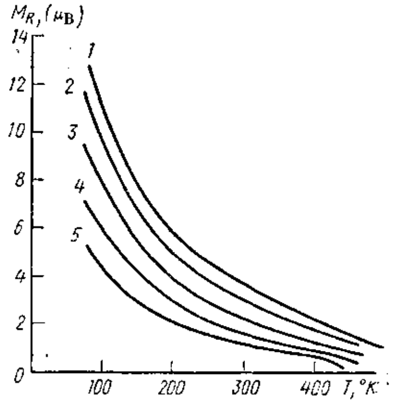

Fig. 3. Temperature dependences of the magnetization of the gadolinium sublattice in the $\{Ga_{3-x}Ca_x\}[Fe_2](Fe_{3-x}Si_x)O_{12}$ ferrite garnets. The notation is the same as in Fig. 1.

The weak $H_{exc}(T)$ dependence at low temperatures, will refine the sharpest change in the magnetization of the rare earth sublattice (Fig. 3), implies that in the substituted gadolinium ferrite garnets the exchange interaction between rare earth ions is not vastly weaker than that between rare earth ions and iron ions; i.e., we can say that we have $\nu \ll \lambda$ in the substituted gadolinium ferrite garnets, and the H_{exc} acting on the gadolinium ions is produced primarily by the iron ions.

The field H_{exc} in all these substituted gadolinium ferrite garnets, except for the composition $x_T = 1{,}2$, orients the magnetic moments of the gadolinium ions in the direction opposite the resultant magnetization of the iron sublattices, i.e., opposite the external field). The magnetizations M_R and M_d are antiparallel.

With $x_T = 1{,}2$, H_{exc} orients the magnetic moments of the gadolinium ions parallel to the magnetization of the resultant iron sublattice (and thus parallel to the external field). Here M_R and M_d are again antiparallel, although the magnetic moments by the sublattice d in the composition $x_T = 1{,}2$ is less than that of the *a* sublattice.

We can therefore assert that the negative c-d exchange interaction is stronger than the negative c–*a* exchange interaction in the substituted gadolinium ferrite garnets, in agreement with conclusions reached by other investigators [3].

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