The possibility of spin reorientation in an iron lattice of $Tb(Fe_{1-x}Rh_x)_2$ quasibinary compounds

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Average values for the molecular magnetic moments of $Tb(Fe_{1-x}Rh_x)_2$ compounds have been determined from magnetic measurements, and local magnetic moments of Fe ions have been determined from nuclear gamma resonance data. It is shown that near $x \approx 0.5$ a partial reorientation of the spins of the Fe ions occurs, as a result of which compensated antiferromagnetic structure is incompletely realized.

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The heavy rare earth metals (HREM) possess very high atomic magnetic moments, but their low Curie points make the practical application of these metals very difficult. In fact, in alloys of intermetallic compounds of HREM with transition metals (TM) where it is possible to obtain high critical temperatures, there is always a ferrimagnetic structure with an antiparallel orientation of the magnetic moments of the HREM and TM sublattices. As a result of this, of course, the overall magnetic moment of the alloy turns out to be too low.

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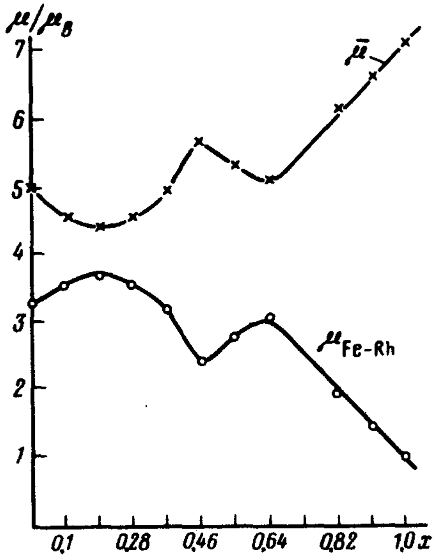

FIG. 1.

Along with this, it is known that in quasibinary intermetallic compounds of the type $R\,(M'_{1-x}M''_x)$ the magnetic properties of the TM sublattice turn out to be very similar to the properties of the corresponding binary systems of alloys $(M'_{1-x}M''_x)$.[1,2] This provided a basis for attempts to use a system of alloys as TM sublattices in which there arises a ferrimagnetic structure, for the purpose of trying to obtain a compensation of the magnetic moment of the TM sublattice and thereby increasing the overall magnetic moment of the alloys. In this respect alloys with 4*d*- and 5*d*- metals having relatively large effective atomic radii and, possibly, a major role for delocalized 4*d*- and 5*d*-electrons in volume interaction processes may be promising.

In this work, we used Fe—RH alloys for this type of system. According to data in Refs. 3 and 4, a transition to the antiferromagnetic state is observed in these binary alloys near an equiatomic FeRh composition.

A system of quasibinary $Tb(Fe_{1-x}Rh_x)_2$ compounds was synthesized. The fusion was carried out in a purified Ar atmosphere in an arc furnace with a permanent electrode for repeated melting. The samples were annealed over 100 hours at 800 °C in a vacuum of better than 10^{-4} mm Hg. A careful x-ray analysis confirmed that the samples investigated were single-phase with type C15 cubic structure.

Measurements of the degree of magnetization were carried out in a vibration magnetometer at a temperature of 4.2 K in fields up to 50 kOe. Nuclear gamma resonance (NGR) was measured in the constant acceleration mode in a spectrometer with an LP-4050 multichannel pulse analyzer. The source was Co^{57} in a layer of stainless steel.

Figure 1 shows the variation of the magnetic moment per formula unit of the compounds determined from the magnetization saturation measured at 4.2 K (curve 1). The value of M_{Tb} in the compound $TbFe_2$ was found to be $M_{Tb} = 8.06\ M_B$.[5] Since

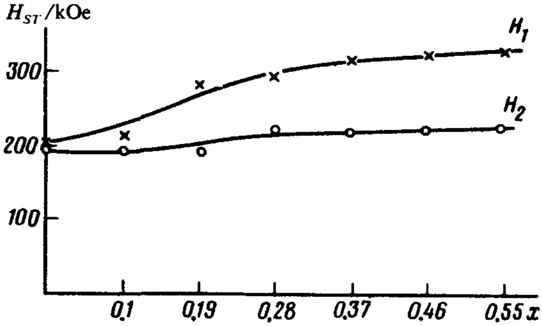

FIG. 2.

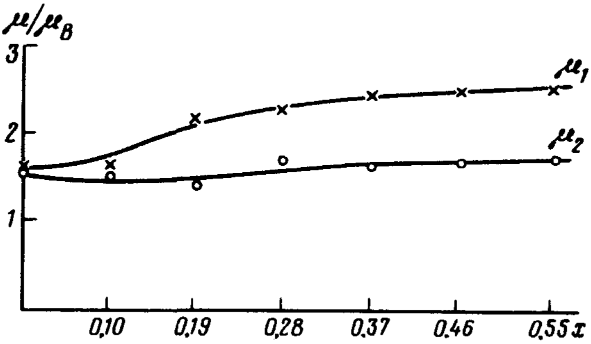

FIG. 3.

a substitution is made in the Fe—Rh sublattice in the $Tb(Fe_{1-x}Rh_x)_2$ quasibinary compounds, while the Tb sublattice remains practically unchanged, it can be assumed that the value for $M_{Tb} = 8.06\ M_B$ will stay constant over the entire range of concentrations investigated. This makes it possible to determine the magnetic moment of the FeRh sublattice, whose concentration variation is also given in Fig. 1 (curve 2). A characteristic of this curve is an increase in the sublattice moment with increasing Rh content up to $x = 0.19$, and a deep minimum near $x \approx 0.5$.

This behavior of the overall magnetic moment of the sublattice may be due to corresponding changes in the local magnetic moments of the Fe and Rh ions, or to changes in their orientation.

The value of M_{Rh} in the $Tb(Fe_{1-x}Rh_x)_2$ compounds may be evaluated, considering the Rh sublattice moment in the critical case of the binary compound $TbRh_2$. The overall moment of this compound is $M = 7.07\ M_B$,[7] which corresponds to $M_{Rh} = 0.5\ M_B$, while it was shown in Ref. 4 that in the Fe—Rh binary compounds the variation of M_{Rh} with concentration was insignificant.

Magnetic moments for the Fe ions may be determined from data for H_{ST} in Fe^{57} nuclei, which have been measured in this work by the NGR technique. The NGR spectra for $Tb(Fe_{1-x}Rh_x)_2$ alloys are a superposition of two sextets characterizing the two values for H_{ST}. Figure 2 shows the variation of these fields with Rh content.

According to the figure, H'_{ST} and H''_{ST} increases, which at $x = 0$ is 10 kOe and at $x = 0.19$ is equal to $\simeq 100$ kOe, and is nearly constant for further increases in x. The value of ΔH at $x = 0$ (~ 10 kOe) may be explained by the difference in the dipole contributions of H_{ST} for the lattice points with a different direction for the easy-magnetization axis. However, the value $\Delta H \approx 100$ kOe which is observed for $x = 0.19$ still cannot be explained by this reason alone. In order to explain this difference it is apparently necessary to assume the existence in the Fe—Rh sublattice of two values of M_{Fe} for the Fe ions with a different Rh environment, as in the binary alloys of Fe—Rh,[4] where $M'_{Fe} = 3.14\ M_B$ and $M''_{Fe} = 2.5\ M_B$ were determined in the ferromagnetic state.

In the case of RFe_2 compounds the values of H_{ST} for Fe^{57} nuclei are almost completely determined by the values of M_{Fe},[9,10] and vary little with the mean alloy magnetization. When other transition metals are substituted for Fe, the influence of the mean magnetic moment for the matrix also begins to matter. In accordance with this, it is possible to use the empirical relationship

$$H_{ST} = a M_{Fe} + b x \bar{M}$$

for quasibinary $Tb(Fe_{1-x}Rh_x)_2$ compounds. Here $\bar{M}$ is the mean magnetic moment referred to a single atom of the compound. For the "a" and "b" coefficients we can use the values determined for isomorphous $Tb(Fe_{1-x}Co_x)_2$ compounds[5]: $a = 125$ kOe/M_B and $b = 21$ kOe/M_B. The values of M'_{Fe} and M''_{Fe} thus obtained are plotted in Fig. 3 as a function of Rh content. These curves show that increasing the Fe—Rh moment in the sublattice with increasing Rh content up to $x = 0.19$ is due to the increase in M_{Fe}. However, the values of the local magnetic moments of the Fe ions are nearly constant in the region of the deep minimum near $x \approx 0.5$ in the curve for the Fe—Rh sublattice magnetic moment.

Thus, the magnetization and NGR data in the quasibinary $Tb(Fe_{1-x}Rh_x)_2$ compounds lead to the conclusion that, near a composition of $x \approx 0.5$ in the Fe—Rh sublattice, an antiparallel orientation of the local magnetic moments of the Fe and Rh ions occurs, which leads to a significant decrease in the overall lattice moment, and to an increase in the resulting moment for the compound. As was noted earlier, an analogous transition was observed by neutron diffraction analysis in a binary Fe—Rh system.[4,7] It is clear that conclusive support for the assumption made concerning the existence of antiferromagnetism in the Fe—Rh sublattice for the $Tb(Fe_{1-x}Rh_x)_2$ compounds, may only be obtained by using neutron diffraction analysis.

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