Existence of temperature-induced ferromagnetism in Y_2Ni_7 and influence of minor replacements of nickel by aluminum on the magnetic properties of this compound

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Results of a study of the magnetic properties of the intermetallic compound Y_2Ni_7 and of the system $Y_2(Ni_{1-x}Al_x)_7$ ($x \leqslant 0,1$) indicate that in Y_2Ni_7 the Fermi level is located in a region in which the density of states depends strongly on the energy. The temperature-induced ferromagnetism effect detected previously in Y_2Ni_7 has not been observed.

In the last few years, the magnetic properties of the intermetallic compound Y_2Ni_7 have held the interest of investigators. This interest stems from the fact that according to the data of Refs. 1 and 2, Y_2Ni_7 in the ground state is a paramagnet, while ferromagnetic order appears in this compound above 7 K and persists up to the Curie temperature of 58 K. This effect, called temperature-induced ferromagnetism, was earlier predicted by Shimizu[3] on the basis of the band theory of magnetism. This effect is attributable to the characteristics of the density of states of magnetic electrons near the Fermi level, $N(E_f)$.

The density of states of d electrons of Y_2Ni_7 were subsequently calculated, which permitted a theoretical description of the magnetic properties of this compound.[4,5] A majority of theoretical studies have concluded that Y_2Ni_7 has a temperature-induced ferromagnetism, although there is a study[6] which casts doubt on this conclusion. As for the experimental state of this problem, there are contradictions here as well. Temperature-induced ferromagnetism of Y_2Ni_7 was observed in Refs. 1 and 2, and in some samples of this compound in Ref. 7, whereas according to the data of Ref. 8, Y_2Ni_7 is a typical, very weak band ferromagnet.

To determine the magnetic state of Y_2Ni_7, we synthesized this compound and studied its magnetic properties. In addition, the mixed compounds $Y_2(Ni_{1-x}Al_x)_7$ were studied in order to analyze how a shift of the Fermi level and a change in the exchange interactions affect the properties of Y_2Ni_7.

The samples for use in the measurements were produced from the initial elements (purity: Y—99.94%, Ni—99.99%, Al—99.85%) in an induction furnace in a water-cooled copper crucible providing for quasilevitation of the melt. The ingots obtained were vacuum-annealed at 1050 °C for 150–180 h, and the content of impurity magnetic phases was checked by the x-ray and thermomagnetic methods, which made it possible to detect the presence of impurity magnetic phases up to 0.1% and nonmagnetic phases up to 2%. Since the deviation of the composition from stoichiometry can considerably modify the magnetic behavior of Y_2Ni_7, we carried out an optimization of the composition of this intermetallic compound. It was found that the homogeneous region was not observed, and the only single-phase compound was a stoichiometric compound of the composition 2:7. The lattice parameters of this compound (hexagonal structure of Gd_2Co_7 type), $a = 4.945 \pm 0.003$ Å and $c = 36.19 \pm 0.03$ Å, are close to those reported in the literature.[8]

Figure 1a shows the magnetization curves of Y_2Ni_7 at different temperatures. It

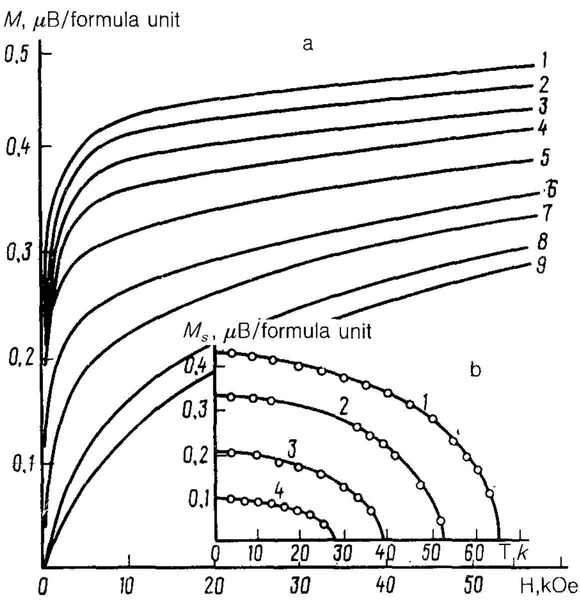

FIG. 1. (a) Magnetization isotherms of the intermetallic compound Y_2Ni_7 at different temperatures: *1* — $T = 4.2$ K; *2* — 13 K; *3* — 25 K; *4* — 35 K; *5* — 45 K; *6* — 55 K; *7* — 60 K; *8* — 66 K; *9* — 69 K. (b) Temperature curves of spontaneous magnetization of certain compositions of the $Y_2(Ni_{1-x}Al_x)_7$ system: 1—$x = 0.0$; 2—0.008; 3—0.016; 4—0.025.

is apparent that the temperature-induced ferromagnetism is not observed in this compound. At low temperatures, the spontaneous magnetization is not zero, and its temperature dependence does not exhibit any anomalies: As the temperature is raised, the spontaneous magnetization decreases steadily and disappears at the Curie temperature of 65 K, which is close to the values of T_c reported elsewhere.[1,7,8] The spontaneous magnetization ($\mu_s = 0.43\mu_B$/f.u.), which is extrapolated to 0 K, is similar to that obtained in Ref. 8, where no temperature-induced ferromagnetism was observed.

A change in the processing of parameters (purity of the initial components, temperature and duration of annealing, etc.) has little effect on the magnetic parameters of Y_2Ni_7.

We suggest that the discrepancy between our results and those of Refs. 1 and 2, where 2 temperature-induced ferromagnetism was detected, is due to the presence of a certain amount of nonmagnetic impurities in the Y_2Ni_7 samples studied, resulting in a shift of the Fermi level toward lower energies and an attenuation of the exchange interactions. According to theoretical calculations,[4,5] this may lead to 2 temperature-induced ferromagnetism. To check this hypothesis, we studied the substitution compositions $Y_2(Ni_{1-x}Al_x)_7$ with low concentrations of aluminum, which do not change the initial Gd_2Co_7-type crystal structure. It was found that minor substitutions of aluminum for nickel greatly reduce the magnetic moment and the Curie temperature, and that compositions with $x \geqslant 0.04$ are paramagnetic (Fig. 1b). Such a marked suppression of ferromagnetism indicates that in Y_2Ni_7 the density of states at the Fermi level and the magnitude of the exchange decrease considerably as a result of substitution. At the same time, however, temperature-induced ferromagnetism does not, as is evident from Fig. 1b, arise in the substitution compositions: They all are normal, very weak band ferromagnets. All the studied compounds of the $Y_2(Ni_{1-x}Al_x)_7$ system satisfy the well-known relation $M_s(T)/M_s(0) = [1 - (T/T_C)^2]^{1/2}$ of the theory of band magnetism. This relation describes the temperature dependence of the spontaneous magnetization of very weak band ferromagnets.[9]

Thus, it follows from our data that the intermetallic compound Y_2Ni_7 is a normal, very weak band ferromagnet and does not exhibit the temperature-induced ferromagnetism effect. Apparently, the absence of this effect in Y_2Ni_7 is due to the influence of spin fluctuations. According to Moriya's estimates,[6] when spin fluctuations are taken into account, temperature-induced ferromagnetism in Y_2Ni_7 can be observed in the case of a nonrealistic dependence of the density of states of d electrons on energy near the Fermi level: $N'(E_f)/N(E_f) \approx N''(E_f)/N(E_f) \approx 4000$ eV^{-1}.

Let us note that the sharp energy dependence of the density of states of d electrons near the Fermi level, which follows from the analysis of the $Y_2(Ni_{1-x}Al_x)_7$ system, makes the compound Y_2Ni_7 a convenient model for studying the characteristics of the magnetic behavior of band electrons as a function of the position of E_f by means of minor substitutions.

When the article was ready for press, a published report[10] stated that the decrease in the magnetic moment of Y_2Ni_7 at low temperatures, which was detected in Ref. 1 and interpreted as the temperature-induced ferromagnetism, was attributed to the presence of small amounts of magnetic impurity (gadolinium) in the test sample.

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