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PHENOMENOM OF THE MAGNETIC INSTABILITI IN SOME MAGNETS WITH COLLECTIVIZED ELECTRONS

ABSTRACT

An effective method of studying the properties of zonal magnets is to affect the magnet by the f-d exchange field. The investigation of the impact of an f-d exchange field on the behavior of zonal metamagnetic YCo_2 was the objectives of this work. Gadolinium was used as a magnetizing element to exclude the effect of a crystal field. Therefore, in this work, the magnetic properties of the system $Y_{1-t}Gd_t(Co_{1-x}A\ell_x)_2$ were studied. The measurement results showed that, as Y is substituted for Gd, the field H_m decreases monotonically. The magnetization of the d-subsystem exceeds that of the f-subsystem $(M_d > tM_f)$, then the magnetic moment of the d-subsystem is oriented parallel to the external field, while the moment of the f-subsystem is antiparallel to the latter, here the $f-d$ exchange interaction leads to a decrease in the metamagnetic transition field. The exchange field H_{f-d} helps the external field with magnetization. When $M_d < tM_f$, the magnetization of the f-subsystem is oriented along the field. The external field does not magnetize the d-subsystem, but demagnetizes it, and then to be magnetized parallel to this field. When these compounds become magnetically ordered, the magnetization degrees of f- и d-subsystems equalize in the concentration zone. The dependence of the magnetic moment of the compositions of the d-subsystem on the content of gadoliniums increases linearly with the increasing content of gadolinium, which is due to the increasing effective field affecting the d-subsystem. The data for the systems with different content of aluminum within an error are on the line.

Keywords: Instability, Metamagnetizm, Magnetization, Exchange Interaction, Critical Field

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1. INTRODUCTION

When studying the phenomenon of magnetic instability in the magnetics with collectivized electrons, the phenomena associated with the magnetic instability of the subsystem of itinerant electrons is of great interest. This phenomenon is determined by the threshold character of ferromagnetism of the system of collectivized electrons, in accordance with which ferromagnetic ordering occurs only when there is fulfilled the Stoner criterion $IN(\varepsilon_F) \geq 1$, where $I(\varepsilon_F)$ is the coefficient of exchange interaction [1]. When the coefficient of exchange interaction is positive, the exchange interaction strives to orient the spins of electrons (and hence the magnetic moments) parallel to each other. As a result, the exchange interaction enhances paramagnetism. As the calculations showed, magnetic susceptibility of the exchange-intensified paramagnet χ_{ex} increases in comparison with the susceptibility of free electron gas χ_p[1]: $\chi_{ex} = \chi_p/(1-\lambda\chi_p)$, where $\lambda = I/\mu_B^2$, is the molecular field coefficient of the $f-d$ exchange interaction.

If in the zero field the system of collectivized electrons was in a paramagnetic state (the Stoner criterion is not fulfilled), in a certain field H_m, where the Stoner criterion begins to be fulfilled, a jump from (metamagnetic) transition of the system of collectivized electrons from the paramagnetic to ferromagnetic state occurs [2 and 3]. This phenomenon is called metamagnetism of collectivized electrons. The magnetic instability of the system of collectivized electrons is manifested in rare-earth intermetallic compounds RCo_2 [2 and 4].

In these intermetallides, the magnetic subsystem of collectivized electrons is in an exchange field acting from the side of the rare-earth subsystem of localized $4f$-electrons. At low temperature this exchange field exceeds the metamagnetic field H_M and hence is in a ferromagnetic state. When the temperature increases, the value of the exchange field decreases and at T_c when the exchange field becomes less than H_M, the system of collectivized electrons jumps to a paramagnetic state [4 and 5]. An effective method of studying the properties of zonal metamagnets is to affect the metamagnet by the f-d exchange field, as, under certain conditions, this allows reducing the critical field of a metamagnetic transition. The investigation of the impact of an f-d exchange field on the behavior of zonal metamagnet YCo_2 was the objective of this work. To exclude the effect of the crystalline field, gadolinium was used as a magnetizing element. Hence the magnetic properties of the system $Y_{1-t}Gd_t(Co_{1-x}A\ell_x)_2$ were studied in this work.

2. RESEARCH SIGNIFICANCE

In the study on the problem of why subsystem of itinerant d-electrons in intermetallic compounds are magnetically unstable, much attention has been focused on the systems RCo_2, where R is a rare earth or yttrium. In these compounds, a d-electron subsystem forms as a result of $3d$-$5d$ hybridization ($3d$-$4d$ in the case of YCo_2) of the cobalt and rare earth d-electrons. For this subsystem, the density of d-states at the Fermi level and the magnitude of $d-d$ exchange are such that the criterion for appearance of itinerant ferromagnetism (the Stoner criterion) is not fulfilled. Because of this, the compounds with nonmagnetic rare earths or yttrium and lutetium, are exchange-enhanced itinerant paramagnets. An important feature of the magnetic behavior of YCo_2 and of $LuCo_2$, is the fact that these compounds are metamagnets, i.e., they convert discontinuously to a ferromagnetic state at a field H_m, the so-called metamagnetic transition field. This transition, which has been observed experimentally, takes place in fields $H_m \sim 10^6$Oe, and is explained by peculiarities in the energy dependence of the density of states $N(\varepsilon)$ of the d-electrons near the Fermi level which cause $N(\varepsilon)$ to increase in a magnetic field. In The RCo_2 intermetallics with magnetic rare earths, both magnetic subsystems- the localized $4f$ electrons of the rare earths and the itinerant d-electrons are magnetically ordered. In this case, the magnetic ordering of itinerant subsystem is extrinsic, and is due to a magnetizing molecular field acting on the d-subsystem. This field, which arises from the f-subsystem of the magnetic rare earth atoms, is larger than the metamagnetic transition field H_m for all R. If we dilute the rare earth f-subsystem with nonmagnetic yttrium, we can decrease this molecular field acting on the itinerant subsystem, and follow the influence of $d-d$ exchange on the properties of the d-subsystem.

3. EXPERIMENTAL METHOD-PROCESS

The basic properties of studied compounds $Y_{1-t}Gd_t(Co_{1-x}A\ell_x)_2$ can be theoretically discussed in the framework of the average field model. Let us consider the zonal d-subsystem of these compounds in the scope of the Wohlfahrt model of weak zonal ferromagnetism [4 and 6]. If the magnetization of the d-subsystem is more than that of the f-subsystem ($M_d > tM_f$), the magnetic moment of the d-subsystem is oriented parallel to the external field, while the moment of the f-subsystem is antiparallel to it, and the $f-d$ exchange interaction leads to a decrease in the metamagnetic transition field

$$H_M(t) = H_M(O) - (-\lambda_{fd} t M_f) \quad (1)$$

If the magnetization of the d-subsystem is less than that of the f-subsystem ($M_d < tM_f$), the magnetic moment of the d-subsystem is oriented antiparallel to the external field, while the moment of the f-subsystem - along the field. Then, when the external field is applied, the d-subsystem is first demagnetized and then established in parallel to the external field, and the $f-d$ exchange field causes an increase in the field of the metamagnetic transition

$$H_M(t) = H_M(O) + (-\lambda_{fd} t M_f) \quad (2)$$

Polycrystalline samples of intermetallic compounds $Y_{1-t}Gd_t(Co_{1-x}A\ell_x)_2$, where $0 \le t \le 0.20$ and $x = 0, 0.05, 0.07, 0.085, 0.105$, were smelted in an induction furnace in the atmosphere of spectrally pure argon in a water-cooled copper crucible under quasi-levitation. The magnetization was measured in static magnetic fields up to 60 kOe and pulse magnetic fields up to 300 kOe over the range from 4.2K to 300K. The magnetic susceptibility was measured in weak alternating fields over the same temperature range.

4. RESULTS AND DISCUSSION

The measurement results showed that, as the concentration of gadolinium increases, the metamagnetic transition field H_M decreases. At concentrations $t \ge 0.04$ these compounds possess spontaneous magnetization. In the magnetically ordered area, at relatively low concentrations of gadolinium ($0.04 \le t \le 0.06$), spontaneous magnetization is small, and, in the field, a metamagnetic transition from the weakly ferromagnetic to strongly ferromagnetic state occurs. There are not observed metamagnetic transitions at high concentration of gadolinium ($t \ge 0.06$): in the zero field, such compounds are in a strongly ferrimagnetic state. Saturation magnetization decreases as the concentration of gadolinium increases up to $t_c \approx 0.17 \div 0.18$, and then increases with the further increase in the concentration of gadolinium. Like in the compositions with low content of aluminum, close to this concentration, transitions from the noncollinear ferromagnetic to noncollinear phase in the external magnetic field are observed. In other $Y_{1-t}Gd_t(Co_{1-x}A\ell_x)_2$ systems with high concentration of aluminum $x = 0.07, 0.105$ the metamagnetic transition field also reduces with the increasing concentration of gadolinium; then there is formed a weakly ferrimagnetic phase replaced by a strongly ferromagnetic phase. The difference is that, as the concentration of aluminum increases, the metamagnetic transition field decreases, and concentration areas of the existence of paramagnetic and weakly ferromagnetic phases become narrower.

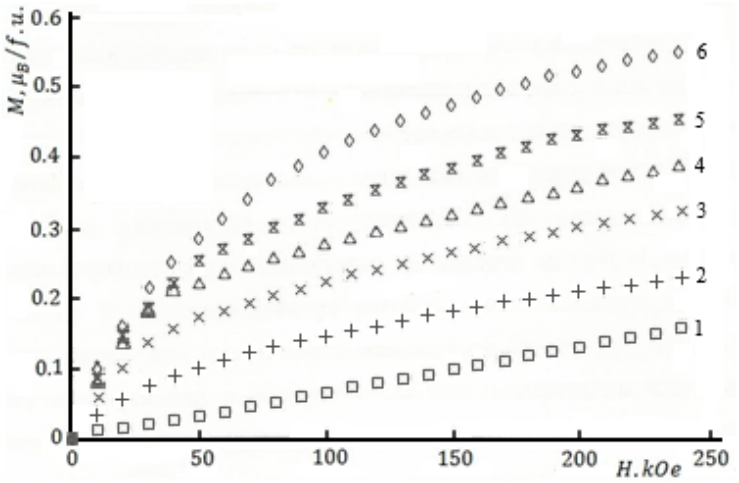

Figure 1. Magnetization curves of the compounds $Y_{1-t}Gd_t(Co_{0.95}A\ell_{0.05})_2$ at $4.2K$ And $t = 0.00(1), 0.02(2),\ 0.04(3),\ 0.06(4),\ 0.08(5), 0.10(6)$

The figure (Figure 1) shows as an example the field dependence of the magnetization $4.2K$ for certain compounds belonging to the system $Y_{1-t}Gd_t(Co_{0.95}A\ell_{0.05})_2$. It is clear that for small replacement by gadolinium $t < 0.12$) there is no spontaneous magnetization. Increasing gadolinium content leads to increased weak-field susceptibility; the magnetization curves of the compounds with gadolinium become nonlinear, and exhibit a tendency toward saturation in strong fields. Analysis shows that these compositions are cluster spin glasses.

Figure 2 shows magnetization curves of some compositions of the system $Y_{1-t}Gd_t(Co_{0.915}A\ell_{0.085})_2$ at $4.2K$. It is evident that compound $Y(Co_{0.915}A\ell_{0.085})_2$ is a zonal metamagnet (Figure 2, curve 1). The critical field of metamagnetic transition for this compound makes up $225kOe$. It is seen that, as Gd replaces Y, field H_M decreases monotonously, and at concentrations $t \geq 0.04$ these compounds possess spontaneous magnetization. This happens due to that the exchange field H_{f-d} helps the external field with magnetization.

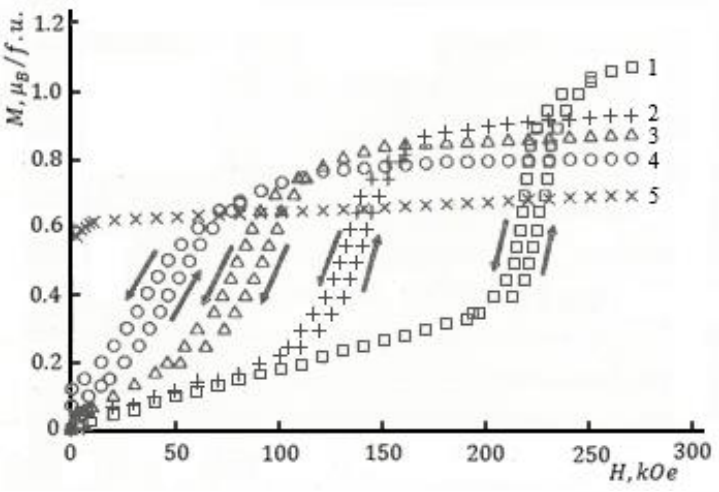

Figure 2. Magnetization curves of the compounds $Y_{1-t}Gd_t(Co_{0.915}A\ell_{0.085})_2$ at $4.2K$ and $t = 0.00(1), 0.02(2), 0.03(3), 0.04(4), 0.06(5)$

It is important to note that, in this system, at the given concentrations of gadolinium, magnetization of the d-subsystem is directed along the field. The transition field in substituted compositions is very simply related to the metamagnetic transition field of pure $Y(Co_{1-x}A\ell_x)_2$ compounds:

$$H_M(t) = H_M(O) - \lambda_{fd} t \mu_f \quad (3)$$

where t is the concentration of gadolinium; μ_f is the magnetic moment of Gd; λ_{f-d} is the molecular field coefficient [7]. The calculations showed that, already in the fields $\sim 30kOe$, μ_f can be considered equal to $7\mu_B$ with high accuracy. From this it is easy to determine the molecular field coefficient, which turned out to be practically independent of the concentrations of Gd and $A\ell$ [8 and 9].

A completely different pattern of magnetization is observed when $M_d < M_f$ (Figure 3). In such a case, the external field demagnetizes the d-subsystem and does not magnetize it, and there are observed no metamagnetic transitions.

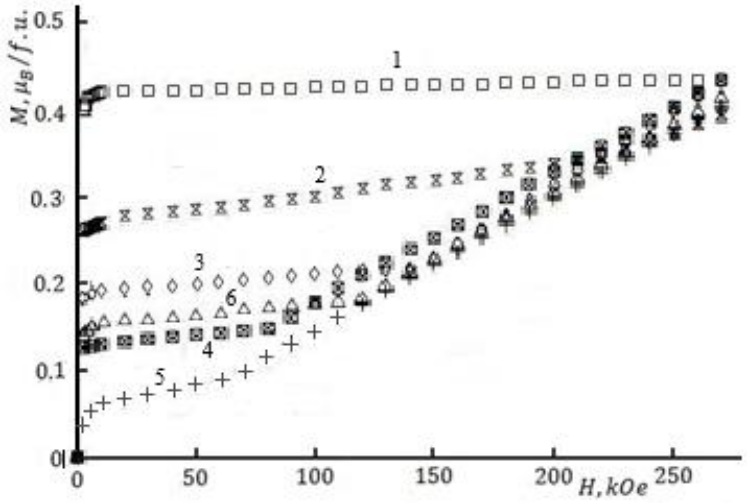

Figure 3. Magnetization curves of the compounds $Y_{1-t}Gd_t(Co_{0.915}A\ell_{0.085})_2$ at $4.2K$ and $t = 0.12(1),\ 0.14(2), 0.15(3), 0.16(4), 0.18(5),\ 0.20(6)$

In the zero field, such compounds are in a strongly ferrimagnetic state. In most systems it corresponds to the concentration of $10 \div 14\,\%\,Gd$. A specific feature of all studied samples is that saturation magnetization decreases with the increasing concentration of gadolinium, and at about 18 at.%Gd, the degrees of magnetization of f- and d-subsystems become equal and then increase with further increase in the concentration of gadolinium. In the vicinity of this concentration, the transitions from a collinear ferrimagnetic phase to a noncollinear phase in the external magnetic field take place. Near the points of magnetic compensation field induced noncollinear magnetic structures can be observed. Based on these data and using a simple formula $H_{c1} = \lambda_{fd}|M_f - M_d|$, the constant λ_{fd} can be determined.

Figure 4 shows the dependences of the magnetic moment of d-subsystem of compositions in the strongly ferromagnetic state on the concentration of gadolinium calculated from saturation magnetization under the assumption that the f-subsystem is saturated. It is seen that M_d increases linearly with the increasing concentration of gadolinium, which is caused by an increase in the effective field affecting the d-subsystem. The data for the systems with different content of aluminum within an error are on the line. From these data, we can find susceptibility and, by linear extrapolation, determine the magnetic moments of d-subsystem: $M_d = 1.2 \pm 0.2\,\mu_a/atom\,Co$.

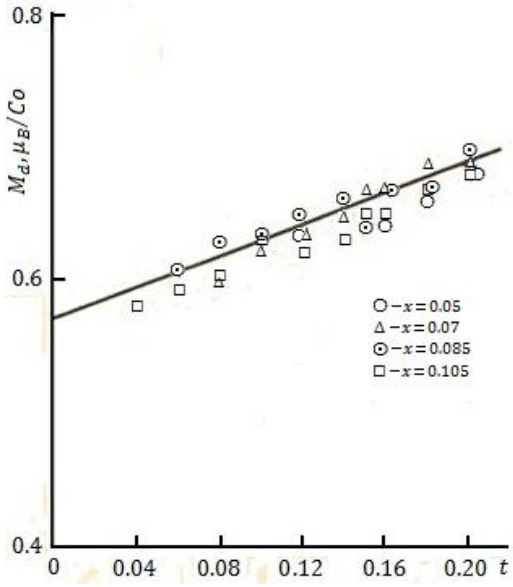

Figure 4. Magnetic moment of the d-subssystem for the compounds $Y_{1-t}Gd_t(Co_{1-x}A\ell_x)_2$ as a function of gadolinium content t at $4.2K$, and $x = 0, 0.05, 0.07, 0.085, 0.105$

5. CONCLUSIONS AND RECOMMENDATIONS

Thus, in $f-d$ systems with a magnetically stable zonal d-subsystem, the $f-d$ exchange interaction causes the effects related to the transition of this subsystem from one magnetic state to another – a transition from a paramagnetic phase with metamagnetism to a weakly ferrimagnetic metamagnetic phase occurs as the gadolinium content increases, followed by a strongly ferrimagnetic phase. In paramagnetic compounds $Y(Co_{1-x}A\ell_x)_2$, the $f-d$ exchange field emerging with partial substitution of *Gd* for *Y* can both increase and decrease the critical field of the metamagnetic transition depending on the concentration of aluminum. With high concentrations of gadolinium, when the d-subsystem transits to the magnetically ordered state due to the $f-d$ exchange interaction, in this system, there are observed the effects characteristic of saturated collinear ferrimagnets: magnetic compensation of sublattices, noncollinear magnetic structures induced by the external field.

NOTICE

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