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Magnetic properties of $Gd_xU_{1-x}Co_2$ system

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The magnetic properties of $Gd_xU_{1-x}Co_2$ system, investigated in the 4-800 K temperature range and fields up to 70 kOe indicated ferrimagnetic order for $x \geq 0.2$. The cobalt magnetic moments, opposite to gadolinium ones and the Curie temperatures decrease with decreasing Gd content. The paramagnetic properties evidence in the high temperature range a Curie-Weiss type behavior and the presence of the effective magnetic moments on Co positions. The paramagnetic behavior of cobalt is analyzed in the spin fluctuations model.

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1. Introduction

The rare earth magnetic properties of the cubic $MgCu_2$ Laves phase compounds of RCo_2 type indicated the Co magnetic moments presence. The $GdCo_2$ compound is ferrimagnetic, the Co magnetic moments are opposite oriented to the Gd 4f magnetic moments [1]. The influence of gadolinium magnetic moments on Co moments is the aim of this paper, studying the magnetic properties of the system obtained substituting uranium for Gd. UCo_2 has a cubic of $MgCu_2$ type crystalline structure and presents a temperature independent susceptibility [2,3]. We follow to determine the magnetic moment on Co atoms in $Gd_xU_{1-x}Co_2$ system to have information about the strength of the exchange interactions for understanding the mechanism of the Co magnetic moment appearance.

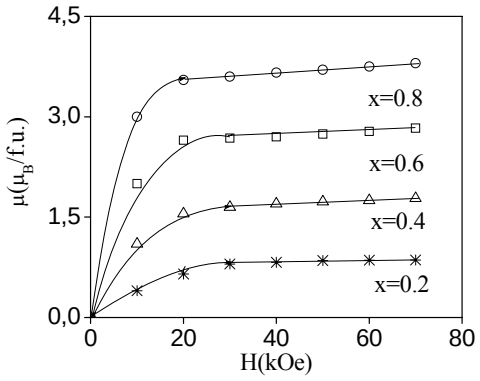

Fig. 1.The field dependence of the magnetization for $Gd_xU_{1-x}Co_2$ system.

2. Experimental

The polycrystalline samples were melted in an argon arc furnace. For a good homogeneity several meltings and a thermal treatment at 1100 K for five days were performed. The X ray diffraction method indicated the presence of the cubic ($MgCu_2$ type) structure. The lattice parameters show an almost linear composition increasing, from 0.699 nm in UCo_2 [3] to 0.724 nm in $GdCo_2$ [4].

The magnetic measurements were carried out in the 4-800 K range and fields up to 80 kOe. The magnetization isotherms lead to the spontaneous magnetization, using the approaching to saturation law: $M = M_s(1 - a/H)$, a being the coefficient of the magnetic hardness. In the paramagnetic region, the correct susceptibility χ values were obtained, according to the relation $\chi_m=\chi+cM_s'H^{-1}$ by extrapolating the measured values χ_m to $H^{-1} \rightarrow 0$. The influence of any magnetic ordering impurity, having saturation magnetization M_s' and concentration c, may be in this way eliminated.

3. Results

$GdCo_2$ is a ferrimagnet with a saturation magnetization of 4.96 μ_B/fu. This is a superposition of 7 μ_B of Gd moment and Co moments antiparallely oriented (about 1 μ_B) [1]; the transition temperature is reported as 395 K [1], 400 K [5]. The systems with $x \geq 0.2$ present the ferrimagnetic order. The field dependence of the magnetization at 4 K is presented in Fig. 1. Assuming that the Gd moment is not altered by uranium substitution, the composition dependence of Co spontaneous moment indicates the influence of Gd magnetic moments as is plotted in Fig. 2. The Curie temperatures presented in Fig. 2, are not linearly decreasing as uranium content is increased. The paramagnetic range measurements, expressed in the temperature dependence of the reciprocal susceptibility are plotted in Fig. 3. In the high temperature domain the susceptibility follows a Curie-Weiss type law. The linear dependence in $1/\chi=f(T)$ starts from high temperatures (about 470 K for x=0.2 and 550 K for x=0.8). The molar Curie constant values calculated from the linear high temperatures dependence of the reciprocal

susceptibility, higher than the values corresponding to the Gd free ion, indicate the presence of the effective magnetic moment on Co positions. The parameters characterizing the paramagnetic state are included in Tabel 1.

Table 1. The Curie temperatures, the magnetic moments, the Co magnetic moments, the molar Curie constants, the effective magnetic moments per Co atom and the exchange field acting on Co moment.

x	1	0.8	0.6	0.4	0.2
T_c(K)	400	355	320	240	190
$\mu\ (\mu_B)/\ fu$	4.96	4	2.96	1.9	0.9
C(emu K/mol)	9.24	7.14	5.48	3.48	1.64
$\mu_{Co}(\mu_B/at)$	1	0.8	0.62	0.45	0.2
$\mu_{eff}(\mu_B/Co)$	2.4	1.82	1.73	1.13	0.5
$H_{\text{int}}(kOe)$	1309	1047	785	524	262

4. Discussion

UCo_2 compound is reported as a temperature independent paramagnet with a susceptibility $\chi = 10,62\times10^{-4} emu/mol$ [2,6]. $GdCo_2$ presents the ferrimagnetic order with the Co moment of 1 μ_B opposite aligned to the Gd 4f moments. The magnetic properties of $Gd_xU_{1-x}Co_2$ system are discussed in the molecular field approximation for two sublattices ferrimagnet [5]. Using the interaction strengths of Gd-Gd, Co-Co and Dy-Co pairs expressed in the coefficients α, β and γ the molecular field which acts on Gd and Co moments are : $H_m^{Gd} = \alpha\mu_{Gd}(T) + 2\gamma\mu_{Co}(T)$, $H_m^{Co} = \gamma\mu_{Gd}(T) + 2\beta\mu_{Co}(T)$. The magnetization of each atom is $\mu_{Gd}(T) = \mu_{Gd}(0)B_{15/2}(x_{Gd})$, $\mu_{Co}(T) = \mu_{Co}(0)B_{1/2}(x_{Co})$ with $x_{Gd} = \mu_{Gd}(0)H_m^{Gd}(1/kT)$ and $x_{Co} = \mu_{Co}(0)H_m^{Co}(1/kT)$. $B(x)$ represents Brillouin function. $\mu_{Gd}(0)$ is 7 μ_B and $\mu_{Co}(0)$ =1 μ_B. Near the Curie temperature the approximation made in B(x) leads to an expression connecting the parameters T_C, $\mu_{Co}(0)$, $\mu_{Gd}(0)$:

$$\left[\beta - \frac{kT_c}{2\mu_{Co}^2(0)}\right]\left[x\alpha - \frac{7kT_c}{3\mu_{Gd}^2(0)}\right] - \frac{7kT_c}{3\mu_{Gd}^2(0)} - x\gamma^2 = 0,$$

x being Gd concentration. Assuming that the interaction parameters α, β and γ remain unchanged by Gd substitution, $\mu_{Co}(0)$ values were determined . α, β and γ constants were those obtained for $GdCo_2$ [5] and T_c were our measured values. The calculated $\mu_{Co}(0)$ values for different composition, are presented in Fig. 2 and may be compared with the experimental ones. The intense variation of the experimental Co moment with the gadolinium composition supports the statement that the molecular field H_{int} acting on the Co moment is principally due to the interaction with the localized 4f spins and depends on the Gd magnetic moment $H_{Co} = xNJ_{GdCo}(g_J - 1)J\mu_B$. J is quantum number of the total angular momentum of Gd 4f electrons, g_J represents Landé's factor, N is Avogadro's number. The spin-spin exchange interaction constant J_{GdCo} expressing the interaction between the pairs Gd-Co has the value of -135 mol fu/emu as it was reported in Ref. [7]. The internal field in $GdCo_2$ is 1309 kOe. The variation of Co moment with the internal field is presented in Fig. 4 and compared with the values from similar system where Gd is substituted by nonmagnetic elements (yttrium) [7,8]. Comparable trend shows the equivalent effects of the exchange field on Co atoms in inducing magnetic moments on Co positions.

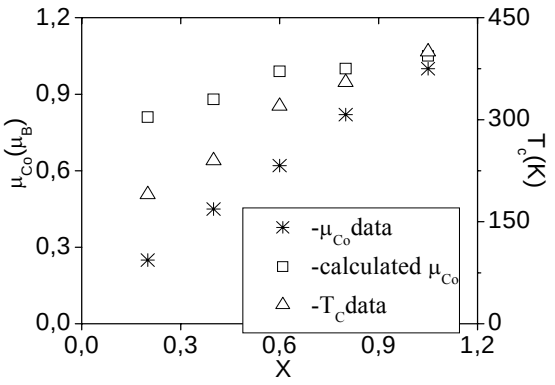

Fig. 2. The composition dependence of Co moments and the Curie temperatures for $Gd_xU_{1-x}Co_2$ system.

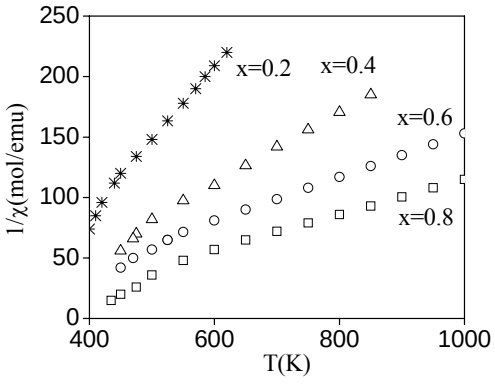

Fig. 3. The temperature dependence of the reciprocal susceptibility for $Gd_xU_{1-x}Co_2$ system.

In the paramagnetic region the behavior of Co is similar to that in exchange enhanced paramagnets $LuCo_2$ and YCo_2 [9]. Over a characteristic temperature T* a linear Curie-Weiss law in the temperature dependence of 1/χ is evidenced. This behavior is discussed in the self

consistent (SCR) of the spin fluctuations theory [10]. According to this, the average amplitude of the spin fluctuations has increasing values as T increases until reaches a superior limit at T*. Over this temperature the amplitude of the spin fluctuations becomes constant, the system presents temperature induced moments and the magnetic properties are described by a Curie-Weiss law. Over the transition temperature in the $Gd_xU_{1-x}Co_2$ system, cobalt presents an exchange enhanced susceptibility and over T* there are temperature induced moments.

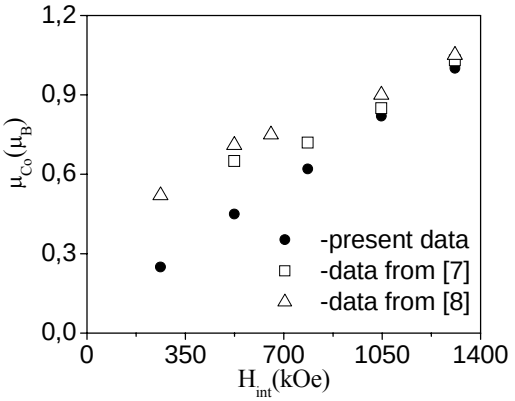

Fig. 4. The Co magnetic moment as a function of internal field.

The low values of μ_{eff}/Co atom in $Gd_xU_{1-x}Co_2$ system, are reported in other systems [11,12]. As it was suggested [11] two mechanisms may be considered. Low gadolinium content generates unsaturated spin fluctuations because the exchange enhancement factor of cobalt susceptibility is not high enough. In gadolinium rich systems the internal field may determine the quenching of the spin fluctuations. The competition between these two mechanisms [11] may explain the small composition variation of Co effective moments.

5. Conclusions

The large internal field of 4f ordered magnetic moments of Gd may induce Co moments, opposite aligned to the Gd ones and the systems are ferrimagnetically ordered. The Co moments are decreasing as gadolinuim is substituting by uranium. These moments are induced by the exchange field exerted by the localized 4f moments. In the paramagnetic region, over T*, the Co effective magnetic moments are present and the spin fluctuations model may describe the paramagnetic behavior of cobalt in the ferrimagnetic $Gd_xU_{1-x}Co_2$ ($x \geq 0.2$) system.

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