Vol. 85 (1994) *ACTA PHYSICA POLONICA A* No. 2

Proceedings of the European Conference "Physics of Magnetism 93", Poznań 1993

SUSCEPTIBILITY OF THE RARE EARTH TERNARY $RNiSi_2$ AND $RNiGe_2$ COMPOUNDS*

A. Gil

Institute of Physics, Cracow Technical University
Podchorążych 1, 30-074 Kraków, Poland

A. Szytuła, Z. Tomkowicz, K. Wojciechowski

Institute of Physics, Jagiellonian University, Reymonta 4, 30-59 Kraków, Poland

and A. Zygmunt

W. Trzebiatowski Institute of Low Temperatures and Structure Research
Polish Academy of Sciences, Okólna 2, 50-950 Wrocław, Poland

The ternary silicides and germanides $RNiX_2$ (R — rare earth, X = Si or Ge) with the orthorhombic $CeNiSi_2$-type structure are investigated by magnetometric measurements. $CeNiSi_2$, $CeNiGe_2$ and $SmNiGe_2$ have a nonmagnetic state in low temperatures. The compounds with R = Pr and Nd are ferromagnets while those containing R = Gd–Er are antiferromagnets. The de Gennes scaling of the Néel temperatures indicates a strong influence of the crystalline-electric field effects.

PACS numbers: 75.30.Cr

1. Introduction

During the last two decades rare earth ternary RTX_2 intermetallic compounds where R is a rare earth, T is a transition *nd* metal and X = Si,Ge are the subject of intensive studies [1]. These compounds crystallize in an orthorhombic $CeNiSi_2$-type structure [2].

In this work the results of magnetic measurements of $RNiX_2$ (X = Si,Ge) compounds are presented.

2. Experiment and results

$RNiX_2$ compounds were prepared by arc melting of the stoichiometric amounts of the constituent elements (purity 99.9% for rare earth and nickel, 99.99% for silicon and germanium).

---

*This work was partially supported by the grant 2-0083-91-01 of the Committee for Scientific Research.

The powder X-ray diffraction analysis was performed on all samples using DRON-3 diffractometer equipped with Co K_α radiation. The obtained data indicate that the $RNiSi_2$ and $RNiGe_2$ compounds crystallize in an orthorhombic $CeNiSi_2$-type structure (space group *Cmcm*). The determined lattice parameters are in good agreement with those presented in the papers [2, 3].

The magnetic susceptibility of all $RNiSi_2$ and $RNiGe_2$ compounds was measured in the temperature range 2–300 K using a vibrating sample magnetometer in low and high (up to 50 kOe) magnetic fields. The temperature dependence for a few $RNiSi_2$ (R = Gd–Er) compounds is shown in Fig. 1. In low temperatures a maximum characteristic for an antiferro- to paramagnetic transition is observed. $CeNiSi_2$, $CeNiGe_2$ and $SmNiGe_2$ compounds are paramagnets in the whole temperature range, and compounds with Pr and Nd are ferromagnets in low temperatures.

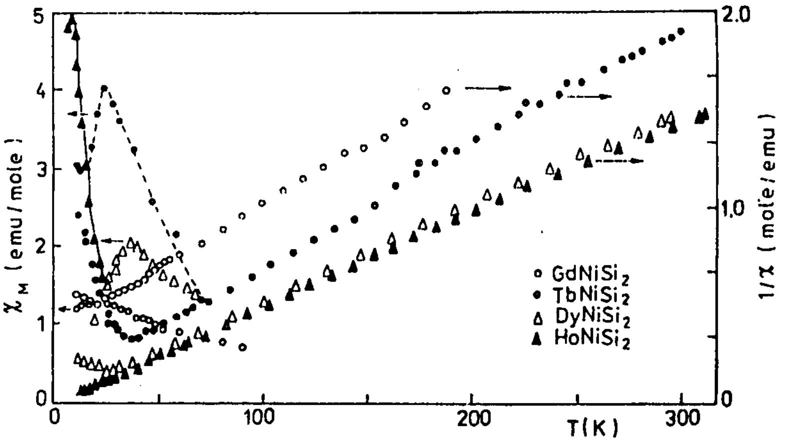

Fig. 1. The temperature dependence of the magnetic susceptibility and reciprocal susceptibility for $RNiSi_2$ compounds (R = Gd,Tb,Dy,Ho).

Above critical temperature of the magnetic ordering T_N or T_C the magnetic susceptibility satisfies the Curie–Weiss law. The effective magnetic moment $\mu_{\rm eff}$ and paramagnetic Curie temperature Θ_p obtained from the Curie–Weiss fit to the experimental data for all these compounds and values of the critical temperature of magnetic ordering are given in Table. The values of the effective magnetic moments are close to the free ion values $g\sqrt{J(J+1)}$ (see Table). It indicates that magnetic moments are localized only on the rare earth atoms and it agrees with the results of the neutron diffraction studies [4, 5]. A small disagreement observed for the experimental values and the rare earth's free-ion values of the magnetic moments results from a strong coupling of the conduction electrons with the localized moments. In such a case, the RKKY theory gives the following formula for the effective magnetic moment:

$$\mu_{\rm eff} = g_J \mu_B \sqrt{J(J+1)}\,[1 + J_{\rm sf} N(E_F)(g_J - 1)/g_J]\,,$$

TABLE

Magnetic data for $RNiSi_2$ and $RNiGe_2$ compounds.

	$RNiSi_2$				$RNiGe_2$				
R	TMO (a)	$T_{C,N}$ [K]	Θ_p [K]	μ_{eff} [μ_B]	TMO (a)	$T_{C,N}$ [K]	Θ_p [K]	μ_{eff} [μ_B]	$g\sqrt{J(J+1)}$
Ce							−20.8	2.5	2.54
Pr	F	22	+19.1	3.50	F	15	13.8	3.26	3.58
Nd	F	12	20.6	3.54	F	15	+7	3.31	3.62
Sm	AF	9.8	−4	0.88			−13.6	0.97	0.85
Gd	AF	21	−33	9.4	AF	24.5	−33	8.6	7.94
Tb	AF	37.6	−17	9.84	AF	42	−31.5	10.57	9.72
Dy	AF	25	−12	11.1	AF	22	−12	10.96	10.65
Ho	AF	10	+0.35	10.6	AF	7.6	−5	10.71	10.61
Er	AF	3.1	+4	9.56	AF	2.5	−2	9.69	9.58

[a] TMO — type of magnetic ordering.

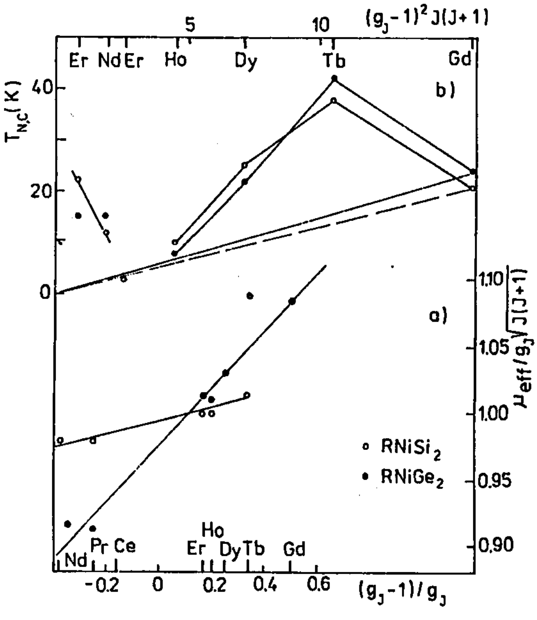

Fig. 2. The ratio of the experimental effective moment to the free-ion moment as a function of the $(g_J - 1)/g_J$ parameter (lower part of the figure) and magnetic ordering temperatures and paramagnetic Curie temperatures of $RNiSi_2$ and $RNiGe_2$ compounds as a function of the rare earth ion (upper part of the figure).

where g_J is the Lande factor, $N(E_F)$ is the conduction electron density of states per atom at the Fermi surface for one spin direction and J_{sf} is the effective s–f exchange interaction due to the direct exchange and the s–f mixing. In Fig. 2a, we have plotted the ratio of experimental effective moments to the free-ion moments as a function of the $(g_J-1)/g_J$ parameter. From Fig. 2a it is seen that $J_{\mathrm{sf}}N(E_{\mathrm{F}})$ is +0.38 for $\mathrm{RNiSi_2}$ and +1.08 for $\mathrm{RNiGe_2}$.

In these compounds the R–R interatomic distances are long enough to exclude any direct magnetic interaction. Therefore at low temperature the observed magnetic ordering is stabilized by long range interactions, probably of the RKKY--type. In the RKKY model in isostructural series of compounds, the paramagnetic Curie temperature Θ_{P} or the magnetic ordering temperatures T_{N} or T_{C} should be proportional to the de Gennes function $G=(g_J-1)^2J(J+1)$ [6]. Presented in Fig. 2b the results for both groups of compounds indicate that the de Gennes scaling is not obeyed. The shift of T_{N} for compounds containing Tb may result from the crystal electric field effects (CEF). In such case the crystalline electric field terms should be added to the exchange Hamiltonian. On the basis of the Noakes and Shenoy model [7] the CEF model with a simple B_2 term produces the maxima in T_{N} for Tb compounds.

References

[1] A. Szytuła, in: *Handbook of Magnetic Materials*, Ed. K.H.J. Buschow, Vol. 6, North-Holland, Amsterdam 1991, Ch. 2, p. 85.

[2] O.I. Bodak, E.I. Gladyshevskii, *Kristallografiya* **14**, 990 (1969) [*Sov. Phys.-Crystallogr.* **14**, 859 (1970)].

[3] M. Francois, G. Venturini, B. Malaman, B. Roques, *J. Less-Common Met.* **160**, 197 (1990).

[4] P. Schobinger-Papamantellos, K.H.J. Buschow, *J. Less-Common Met.* **171**, 321 (1991).

[5] W. Bażela, J. Leciejewicz, K. Małetka, A. Szytuła, *J. Magn. Magn. Mater.* **109**, 305 (1992).

[6] P.G. de Gennes, *J. Phys. Radium* **23**, 510, 630 (1962).

[7] P.R. Noakes, G.K. Shenoy, *Phys. Rev. Lett. A* **91**, 35 (1982).