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#### Magnetic properties of TbNi<sub>5</sub> and HoNi<sub>5</sub> single crystals

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**Résumé.** — Les mesures d'aimantation et de susceptibilité suivant les axes **a**, **b** et **c** ont été effectuées sur des monocristaux hexagonaux de  $TbNi_5$  et  $HoNi_5$ . Les quatre paramètres de champ cristallin ainsi que la polarisation de la bande d du nickel ont été déterminés.

Abstract. — Magnetization and paramagnetic susceptibility measurements along the a, b and c axes were performed on single crystals of the hexagonal ferromagnetic TbNi<sub>5</sub> and HoNi<sub>5</sub> compounds. The four crystal field parameters as well as a polarization of the d-band of nickel were determined.

1. Introduction. — The RNi<sub>5</sub> (R = rare earths or Y) compounds crystallize in the hexagonal CaCu<sub>5</sub>type structure. Magnetic measurements on polycrystalline samples [1] and specific heat study [2] have shown the importance of the crystalline electric field (C.E.F.) effects in these compounds. YNi<sub>5</sub> is a Pauli paramagnet, with a strong enhanced susceptibility. With magnetic atoms, especially in GdNi<sub>5</sub>, a weak polarization of the d-band is observed [3]. In this paper we present magnetization measurements performed at the Service National des Champs Intenses on single crystals of RNi<sub>5</sub> compounds.

2. Experimental. — In figures 1 and 2 we have reported for  $TbNi_5$  and  $HoNi_5$  the magnetization

versus internal field below  $T_c$  as well as the thermal dependence of the reciprocal paramagnetic susceptibility along the **a**, **b** and **c** axes.

TbNi<sub>5</sub> – **a**([100]) is the easy magnetization direction. The anisotropy in the basal plane is small. The large uniaxial anisotropy is responsible of the difference between the paramagnetic Curie temperature measured along  $\mathbf{c}(\theta_{\parallel})$  and in the basal plane  $(\theta_{\perp})$ .

HoNi<sub>5</sub>. — The magnetization measured in the basal plane is not usual. The difference between the magnetization measured along **a** and **b** which is almost zero in 3 kOe increases with the field and reaches 1  $\mu_{\rm B}$ /HoNi<sub>5</sub> in 150 kOe. The magnetic properties of these compounds are compared on the table with those of ErNi<sub>5</sub> [4].



Fig. 1. — TbNi<sub>5</sub> and HoNi<sub>5</sub> : Magnetization versus internal field; open circles are the experimental values, full lines are the calculated variations.  $\varphi = (\mathbf{H}, \mathbf{M})$  in 150 kOe



Fig. 2. —  $\text{TbNi}_5$  and  $\text{HoNi}_5$ : Thermal variation of the reciprocal susceptibility; open circles are the experimental values, full lines are the calculated variations.

3. Analysis and discussion. — The anisotropy in  $GdNi_5$  being very small [4], the strong anisotropy observed in the  $RNi_5$  compounds can be attributed to C.E.F. on the 4f-electrons. The perturbing Hamiltonian acting on the  $R^{3+}$  ground multiplet is :

$$\begin{aligned} \mathcal{C} &= \left( B_2^0 \ O_2^0 + B_4^0 \ O_4^0 + B_6^0 \ O_6^0 + B_6^6 \ O_6^6 \right) + \\ &+ g_J \ \mu_{\mathbf{B}} \, \mathbf{J} . (\mathbf{H} + n \langle g_J \ \mu_{\mathbf{B}} \, \mathbf{J} \rangle) \,, \end{aligned}$$

where the molecular field coefficient is given by :

$$n = 3 k_{\rm B} T_{\rm c}/g^2 \,\mu_{\rm B}^2 \,J(J+1) \,.$$

The  $B_1^{\text{m}}$ 's were obtained by simultaneous fits of the magnetization curves and the thermal variations of the reciprocal susceptibility. The total perturbing Hamiltonian was diagonalised in the three-dimensional space. The calculation was performed in a self-consistent manner until the calculated value of  $\langle g_J \mu_{\rm B} \mathbf{J} \rangle$  is in agreement with that one used in the expression of the molecular field. The calculated magnetization along the applied field was taken as :

$$\sigma = (\langle g_J \mu_{\mathbf{B}} J \rangle + \mu_{\mathbf{P}} + \chi_{\mathbf{P}} H) \cos \varphi,$$

where  $\varphi = (\mathbf{H}, \mathbf{J})$  and,  $\mu_{\mathbf{P}} + \chi_{\mathbf{P}} H$  represent the polarization of the d-band. As a starting point the value of  $B_2^0$  is given by :

$$B_2^0 = \frac{10(\theta_{\perp} - \theta_{\parallel})}{3(2 J - 1)(2 J + 3)}$$

On the table, we have summarized the results obtained for each compound. The C.E.F. parameters obtained lead to the calculated variations represented in full lines on the figures. Due to the strong anisotropy a 150 kOe applied field along c is not high enough to align the magnetization along the field.

The model used gave us a good account from the magnetic properties of these compounds. Especially the peculiar behaviour observed in HoNi<sub>5</sub> below  $T_c$  when the field is applied in the basal plane arises from the positive sign of  $B_4^0$ . A 1 kOe internal field along **b** is high enough to align the moment which is parallel to the field. The difference observed in higher field originates from a large anisotropy of the magnetization. The C.E.F. parameters calculated in the over simplified point charge model (+ 3e on rare earths and zero on nickel) are reported on the table. The order of magnitude and the sign of  $B_2^0$  and  $B_4^0$ 

Table I. — Magnetic properties of  $\text{TbNi}_5$ .  $\text{HoNi}_5$  and  $\text{ErNi}_5$ . Comparison of crystal field parameters determined from magnetization measurements to those calculated in a point charge model (P.C.M.).  $\Delta$  represents the total splitting of the ground multiplet by the crystal field.

Compounds	TbNis		HoNis		ErNi <sub>5</sub>	
	Exp.	P.C.M.	Exp.	P.C.M.	Exp.	P.C.M.
	_					_
$T_{c}$ (K)	23		4.5	_	10	_
$B_{2}^{0}$ (K)	3.20	2.50	1.15	0.49	- 0.83	- 0.52
$B_{4}^{0}$ (K)	$-0.27 \times 10^{-2}$	$-0.20 \times 10^{-2}$	$0.26 \times 10^{-2}$	$0.47 \times 10^{-3}$	$-0.20 \times 10^{-3}$	$-0.58 \times 10^{-3}$
$B_{6}^{0}(K)$	$-0.45 \times 10^{-4}$	$0.45 \times 10^{-6}$	0	$0.40 \times 10^{-6}$	$0.37 \times 10^{-4}$	$-0.56 \times 10^{-6}$
$B_{6}^{6}$ (K)	$-0.10 \times 10^{-3}$	$0.30 \times 10^{-5}$	$-0.38 \times 10^{-3}$	$0.27 \times 10^{-5}$	$0.10 \times 10^{-3}$	$-0.39 \times 10^{-5}$
⊿ (K)	322	268	314	98	187	91
$\mu_{\mathbf{P}}$ ( $\mu_{\mathbf{B}}$ )	- 1.05		- 0.40		- 0.80	
$\chi_{\rm P} ~(\mu_{\rm B}/{\rm kOe})$	$0.62 \times 10^{-2}$		$0.10 \times 10^{-2}$		$0.75 \times 10^{-2}$	

are the same as those found experimentally, but the sixth order terms are quite different. As a matter of fact the contribution of the conduction electrons with d-character to the C.E.F. must be important. The determinated parameters give account for the high Schottky anomalies observed above  $T_c$  on the

magnetic contribution to the heat capacity of  $HoNi_5$  [2].

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#### References

- NESBITT, E. A., WILLIAMS, H. J., WERNICK, J. H. and SHER-WOOD, R. C., J. Appl. Phys. 33 (1962) 1674.
- [2] SANKAR, S. G., KELLER, D. A., GRAIG, R. S., WALLACE, W. E. and RAO, V. U. S., J. Phys. Chem. Solids 9 (1973).
- [3] GIGNOUX, D., GIVORD, D. and DEL MORAL, A., Solid State Commun. 19 (1976) 891.
- [4] ESCUDIER, P., GIGNOUX, D., GIVORD, D., LEMAIRE, R. and MURANI, A. P., Physica 86-88 (1977) 197.