MAGNETIC NEUTRON SCATTERING INVESTIGATIONS OF TbPd₃ AND OF DyPd₃

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MAGNETIC NEUTRON SCATTERING INVESTIGATIONS OF TbPd$_3$ AND OF DyPd$_3$

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Abstract. Neutron scattering investigations were performed for TbPd$_3$ and DyPd$_3$ in order to study magnetic ordering phenomena and crystal-field splittings. TbPd$_3$ shows below $T_N = 3.1$ K an incommensurate antiferromagnetic spiral type structure corresponding to two wavevectors. For DyPd$_3$ ferromagnetic ordering below $T_C1 = 2.2$ K and a commensurate ferrimagnetic structure below $T_C2 = 1.6$ K is observed.

1. Introduction

The magnetic properties of the intermetallic compounds RPd$_3$ (R = rare earth) have been the subject of several investigations [1-3]. All these compounds crystallize in the AuCu$_3$ structure, and their magnetic ordering temperatures are rather small. This indicates that the interionic exchange in these materials is weak and that we deal to a good approximation with crystal-field only systems. The crystal-field interaction has been derived for most of these compounds and their diluted analogues by inelastic neutron scattering [4-5]; however, detailed information on the magnetic ordering phenomena are missing. Therefore we have started neutron diffraction experiments in order to determine the magnetic structures of the RPd$_3$ compounds. These measurements are complemented by inelastic and diffuse critical neutron scattering experiments. In the present work we present the results obtained so far for TbPd$_3$ and DyPd$_3$.

2. Experimental

Powder samples of TbPd$_3$ and DyPd$_3$ were prepared by rf-heating stoichiometric quantities in an argon atmosphere. A single crystal of TbPd$_3$ and of DyPd$_3$ was grown by recrystallization. The homogeneity and the AuCu$_3$ - structure of the samples was verified by X-ray analysis and by neutron diffraction.

The majority of the neutron scattering experiments were performed at the reactor Saphir at Würenlingen with use of two- and three-axis-spectrometers. The low temperature neutron diffraction experiments for DyPd$_3$ were carried out at Risø National Laboratory, and a preliminary search for crystal-field excitations in DyPd$_3$ was carried out at the ILL Grenoble with use of the time-of-flight spectrometer IN5.

3. Results

Characteristic neutron diffraction patterns observed for polycrystalline TbPd$_3$ exhibits at low temperatures ($T = 1.5$ K) a large number of additional lines compared to the data collected in the paramagnetic state ($T = 30$ K), which is indicative of a complicated incommensurate antiferromagnetic ordering. Dominant neutron intensities of two magnetic reflections of a TbPd$_3$ and of a DyPd$_3$ single crystal are shown in figure 1. There is clear evidence for different critical exponents $\beta_1 = 0.34$ and $\beta_1 = 0.55$ of the corresponding magnetizations below $T_N = 3.1$ (2) K.

Fig. 1. – Temperature dependence of two dominant magnetic peak intensities of a TbPd$_3$ single crystal and of polycrystalline DyPd$_3$. The lines are guides to the eye.

Diffuse critical neutron scattering samples the short-range ordered spin fluctuations and diverges at $T_N$. For small deviations q from the magnetic Bragg peaks we expect to observe maxima at $T_N$ as shown in figure 2 for a single crystal of TbPd$_3$.

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Characteristic neutron diffraction results obtained for polycrystalline DyPd$_3$ are shown in figure 1. DyPd$_3$ orders ferromagnetically below $T_{C1} = 2.2$ (2) K, but the appearance of antiferromagnetic reflections at $T_{C2} = 1.6$ (2) K indicates the development of a commensurate ferrimagnetic structure below $T_{C2}$ (at $T = 0.6$ K : $\mu_{\text{ferro}} = 5.3$ (4) $\mu_B$, $\mu_{\text{antiferro}} = 2.5$ (3) $\mu_B$).

The neutron spectroscopic measurements performed for TbPd$_3$ and DyPd$_3$ confirm the crystal-field level structures derived for the corresponding diluted systems [5]. While for TbPd$_3$ we have not been able to resolve the low-lying crystal-field excitations, we have clearly resolved for DyPd$_3$ the ground-state $\Gamma^{(1)} \rightarrow \Gamma^{(2)}$ transition at 1.8 meV and the excited-state $\Gamma^{(2)} \rightarrow \Gamma_7$ transition at 1.0 meV.

4. Discussion

By combining neutron scattering results from single crystal and polycrystalline samples, we have been able to determine the incommensurate antiferromagnetic structure of TbPd$_3$ with use of a special profile refinement program. The magnetic structure corresponds to two wavevectors $k_1 = (1/3 - \delta, 1/3 - \delta, 1/3 - \delta)$ and $k_2 = (-1/2 + \delta/4, 1/4 + 2\delta, 1/4 + \delta)$ ($\delta = 0.0254$ (2)). The occurrence of two different critical exponents could be an indication to associate $k_1$ with a spiral type ordering of the magnetic moments of the Tb ions and $k_2$ with a modulated ordering of induced magnetic moments of the Pd ions. The result of a neutron diffraction profile calculation is shown in figure 3. On the other hand, DyPd$_3$ orders commensurately: ferromagnetically with a Curie temperature $T_{C1} = 2.2$ (2) K and ferromagnetically below $T_{C2} = 1.8$ (2) K with a wavevector $k = (1/2, 1/2, 0)$. The total magnetic moments of the Tb-ions and of the Dy-ions at $T = 1.5$ K were determined to be $\mu_{Tb} = 5.0$ (2) $\mu_B$, $\mu_{Pd} = 1.4$ (2) $\mu_B$ and $\mu_{Dy} = 5.9$ (4) $\mu_B$, respectively. Thus the magnetic moments are considerably reduced below the free ion values, which cannot be explained by crystal-field effects alone. Presumably quadrupolar interactions are important in these systems. At present we are studying the magnetic excitations of TbPd$_3$ in order to determine the relevant magnetic interactions and thus to understand the complicated magnetic ordering phenomena in these systems.

Acknowledgments

Financial support by the BMFT (F.R.G.) and the Swiss National Science Foundation is gratefully acknowledged.