MAGNETIC BEHAVIOR OF DyBi

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DyBi revealed a behavior similar to that found in DySb. A first-order pseudo-tetragonal deformation of the rocksalt structure occurs at the Néel temperature $T_N = 11.2$ K. At 1.5 K applied fields of the order of 30 kOe induce a transition to the HoP magnetic type. Ferromagnetic order can be achieved with a magnetic field $H \geq 52$ kOe along the [001] direction.

DyBi is one of the rocksalt-type rare-earth pnictides which has not yet attracted much interest. We have investigated DyBi single crystals which were prepared by slow cooling through the melting point. Dy carries 10 f-electrons whose ground state is $^6H_{15/2}$. Between 450 and 900°C the magnetic susceptibility of our sample DyBi No. 8 did indeed agree well with a $J = 15/2$ ground state. The Curie–Weiss law was obeyed with $n_p = 10.58\mu_B$ and $\Theta_p = -8$ K, as compared with the theoretical magneton number $10.65\mu_B$. At lower temperatures deviations from the Curie–Weiss behavior occurred due to the splitting of the ground-state multiplet by the crystal electric field. The overall splitting Γ_6–$\Gamma_8^{(3)}$ is estimated to be ≈ 110 K. DyBi undergoes a first-order phase transition at the Néel temperature $T_N = 11.2$ K. At this temperature the cubic unit cell transforms abruptly, probably to a monoclinic cell which looks tetragonal within the resolution of our diffractometer (fig. 1). On heating the sample through the ordering temperature both the tetragonal and the cubic reflections were present within a range of 0.05 K around T_N. The assumption of monoclinic symmetry of the low-temperature phase is based on the analogy with DySb, which has been thoroughly investigated [1–8].

Not only the structural behavior of DyBi but also the magnetic-field dependence of its magnetization is very similar to that of DySb (fig. 2). At an intermediate field strength the magnetization along [001] switches suddenly to one half of its saturation value (the ground-state level of the molecular-field-split Kramers doublet Γ_6 has a magnetic moment $\approx 9.9\mu_B$). This spin flip occurs at somewhat lower fields along [110] and [111] and leads to $\sqrt{2}$ and $2/\sqrt{3}$ times larger values for the magnetization. This behavior is indicative for the HoP-type spin structure. Since for this magnetic arrangement the magnetic energy with the magnetic field

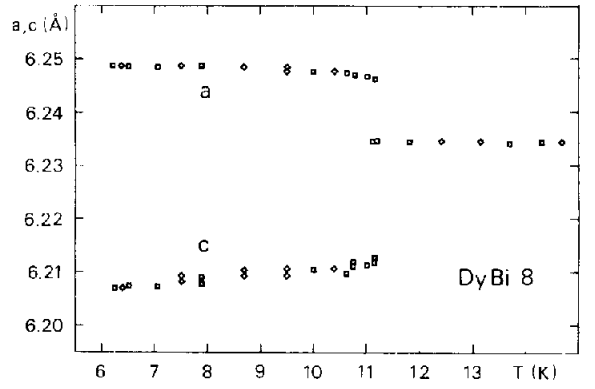

Fig. 1. The pseudo-tetragonal distortion of the rocksalt cell of DyBi below the Néel temperature.

H along [100], [110] and [111] is $-H_{100}\mu/2$, $-H_{110}\mu/\sqrt{2}$ and $-H_{111}\mu/\sqrt{3}$, respectively, the relation $H_{100} \approx \sqrt{2}\, H_{110} \approx 2H_{111}/\sqrt{3}$ should hold for the critical fields, if we neglect the elastic energy, for example. For our sample the spin-flip

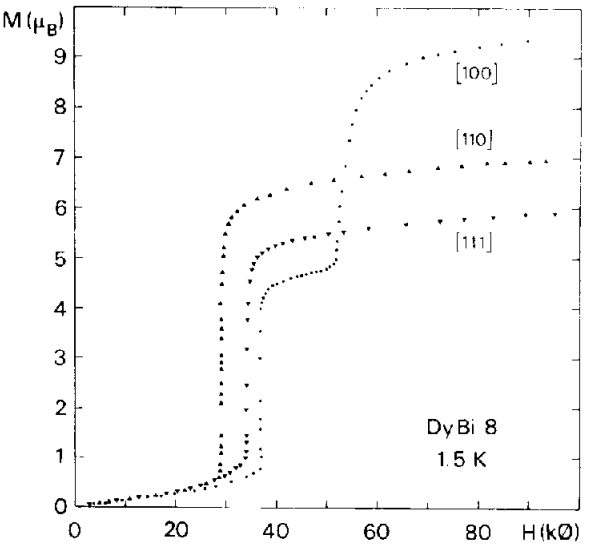

Fig. 2. Dependence of the magnetization upon the effective applied field for DyBi at $T = 1.5$ K.

fields along [100], [110] and [111] amounted to 37, 28.5 and 34 kOe, respectively. The step in exchange energy and magnetic field energy is the same from type II antiferromagnetism to HoP-type ferrimagnetism as in the transition HoP type → ferromagnetism along [100], but the other energy contributions differ [9]. Thus, at 1.5 K with the magnetic field applied along [001] the transition to the completely aligned moment arrangement sets in at 52 kOe. The very large anisotropy energy prevents a ferromagnetic orientation along [110] and [111] and indeed up to 200 kOe no indication of a second transition was found with pulsed fields applied along these directions.

In the dysprosium monopnictides the exchange parameter $\mathcal{J}_1$ is positive for DyP and decreases monotonically with increasing lattice constant a reaching zero near DyBi. The corresponding curve $\mathcal{J}_2(a)$ is almost parallel to $\mathcal{J}_1(a)$ but is negative in the whole range between DyP and DyBi. Based on this $\mathcal{J}_1(a)$ and $\mathcal{J}_2(a)$ dependence one would indeed expect ferromagnetic order in DyN, a HoP-type structure (which in fact is a ferrimagnetic type II arrangement) for a lattice constant somewhere between those of DyP and DyAs, where $\mathcal{J}_1 \approx -\mathcal{J}_2$, and type II antiferromagnetism for DySb and DyBi (fig. 3). In the case of f^9 (Ho^{3+}) and f^{10} (Dy^{3+}) ions the crystal-field potential [9] has a minimum for $J_z \| [001]$. Thus, since the influence of the crystal field dominates, the magnetic moments and hence the easy axis are oriented along [001]. For the lattice distortion the antiferromagnetic interaction along [001] is obviously dominant, giving rise to the tetragonal contraction of the rocksalt cell, whereas the very weak rhombohedral component due to the magnetic [111] layers reduces the symmetry to monoclinic. Substantial lattice distortions in NaCl-type phases usually result from a combination of crystal-field and magnetic interactions. In the case of Dy^{3+} the ground state is an isotropic doublet, Γ_6. Jahn–Teller-like distortions (but with $c/a > 1$ according to Lévy, Fig. 13 of ref. [1]) would be caused by the next higher level, $\Gamma_8^{(1)}$, which is only about 9 K above the ground doublet.

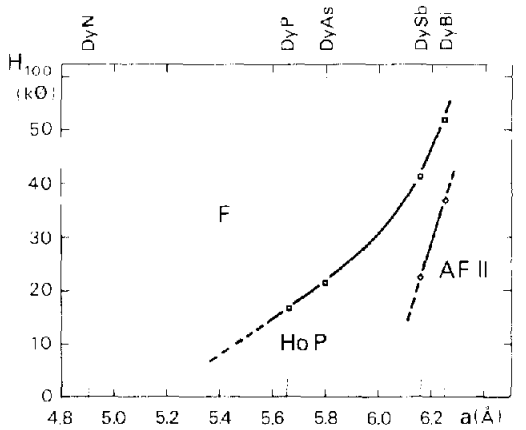

Fig. 3. Magnetic ordering at $T \to 0$ in rocksalt-type Dy pnictides as a function of the unit-cell parameter a.

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