MAGNETIZATION AND ELECTRICAL RESISTIVITY STUDIES OF THE $Ho_cY_{1-c}Sb$-SYSTEM

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Magnetization and electrical resistivity measurements have been performed on the cubic alloy system $Ho_cY_{1-c}Sb$. A molecular-field model, which accounts accurately for most of the magnetic properties of $Ho_cY_{1-c}Sb$, is described. The model predicts a second-order transition to the antiferromagnetic phase at 5.7 K in HoSb followed by a tricritical-like transition at 5.4 K.

HoSb crystallizes in the simple NaCl-structure. Its magnetic properties are found to be determined by a complex competition between a number of different types of interactions [1]. The importance of these has been established by a systematic study of the ground-state properties of the alloy system $Ho_cY_{1-c}Sb$, where c covered uniformly the whole range $0 < c \leqslant 1$.

In the interpretation of the experiments we used the molecular-field (MF) approximation, and we assumed that the random replacement of Ho-ions with the fraction $1 - c$ of non-magnetic Y-ions simply gives rise to a scaling, proportional to c, of the interactions between the Ho-ions. At low temperatures HoSb is a type II-antiferromagnet composed of ferromagnetic (111)-planes, with the moments on adjacent planes oriented antiparallel along a [100]-direction [2]. In the calculations we assumed that the two-sublattice structure is preserved under all circumstances.

The MF-Hamiltonian includes the two crystal-field parameters, the acoustic and optical isotropic exchange, $\mathcal{J}(\boldsymbol{O})$ and $\mathcal{J}(\boldsymbol{Q})$, one optical bilinear anisotropy term, $\mathcal{J}_D(\boldsymbol{Q}) = \mathcal{J}_D$ (which includes the magnetic dipole coupling), and finally acoustic and optical quadrupole parameters, $K(\boldsymbol{O})$ and $K(\boldsymbol{Q})$ (the quadrupole coupling is assumed to be isotropic). In general, three more quadrupole terms are allowed by symmetry in the case of the two-sublattice cubic structure, but in the present context these further terms may be ignored (a more detailed discussion of the MF-Hamiltonian is given in ref. [1]).

The initial susceptibility was determined as a function of c by the Faraday method in the range 1.6–300 K. From these results we deduced the noninteracting susceptibility of the Ho-ions, χ_0, together with $\mathcal{J}(\boldsymbol{O})$. The Néel temperature, T_N, as a function of c was established by magnetization and electrical resistivity measurements (see fig. 1) down to $c = 0.4$. In the model T_N is determined by

$$\chi_0(T = T_N)(\mathcal{J}(\boldsymbol{Q}) - \mathcal{J}_D) = 1/c, \qquad (1)$$

where $\mathcal{J}_D$ is small compared with $\mathcal{J}(\boldsymbol{Q})$.

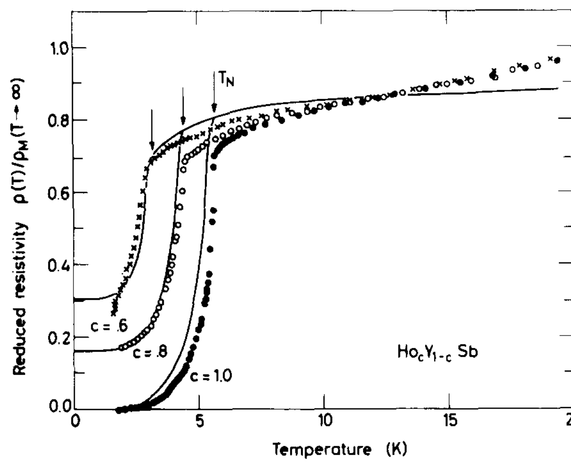

Fig. 1. The electrical resistivity of $Ho_cY_{1-c}Sb$ relative to the spin–disorder resistivity, $\rho_M(T \to \infty)$. The experimental results have been scaled to agree with the calculated curves at 2 and 12.5 K. Above 12.5 K the phonon scattering starts to be important. Within the absolute uncertainties $(1/c)\rho_M(T \to \infty)$ is found to be a constant, and the value of (2.6 ± 0.2) $\mu\Omega$cm compare very well, after the appropriate scaling, with the value deduced in the equivalent system $Tb_cY_{1-c}Sb$ [5]. In the calculations we have neglected the dispersion of the MF-levels and the electron–quadrupole interaction (see ref. [5] for more details). The former approximation causes a systematic c-dependent error, which above T_N is comparable with the discrepancy occuring if k_F is small, as found in the case of $Tb_cY_{1-c}Sb$ [5]. The calculations indicate that the variation of the resistivity reflects the transition at T_N (the calculated values are shown by the arrows) rather than the one at T_N'.

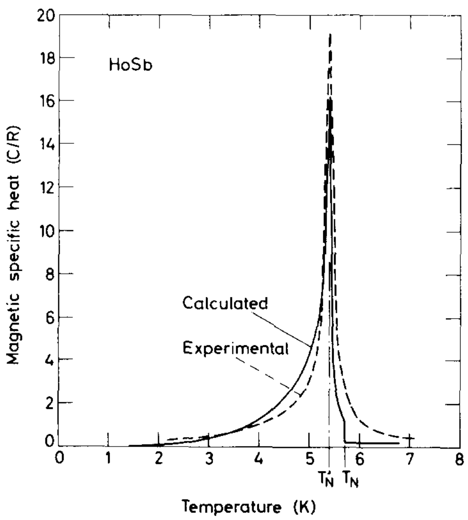

Fig. 2. The low-temperature specific heat of HoSb. The dashed curve shows the experimental results of Taub and Williamson [6]. The MF-result (solid line) exhibits a small jump at T_N (weak second-order transition) followed by a very strong, almost tricritical-like, peak at T'_N. The comparison is satisfactory, if it is assumed that the *small* peak expected experimentally at T_N is smeared out due to the strong one occuring at T'_N.

The bulk magnetization parallel to the field applied along the symmetry axes was measured at 1.6 K for all concentrations. The results obtained when the field was applied along the easy [100]-axis in HoSb showed the presence of an intermediate phase, which according to the MF-calculations should be very similar to the flop-side spin structure found in HoP [2]. These results establish the consistency of the assumed values of $\mathcal{J}(\boldsymbol{Q}) - \mathcal{J}(\boldsymbol{O})$, B_4^0 and B_6^0, and in addition determine a linear combination of $\mathcal{J}_D$ and $K(\boldsymbol{Q}) - K(\boldsymbol{O})$. $K(\boldsymbol{O})$ was then determined from the magnetostriction measurements of Lüthi et al. [3], neglecting possible electronic (intrinsic) contributions to $K(\boldsymbol{O})$.

The last condition on the two-ion anisotropy parameters was obtained by a closer examination of the phase transition in HoSb. This has been studied by Taub and Parente [4] using neutron diffraction. We found that the observed continuous variation of the order parameter indicates that just below T_N the moments lie in the (111)-planes and not along a [100]-axis. At a slightly lower temperature T'_N, the direction (and the magnitude) of the moments changes quite abruptly so to be almost along a [100]-direction. This modification results from a finite, negative value of $\mathcal{J}_D$. The transition temperatures $T_N = 5.70$ K and $T'_N = 5.40$ K which we deduced from the neutron diffraction results are consistent with those obtained from other experiments, see figs. 1 and 2.

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