Low-Temperature Magnetic Behavior of HoRh₄B₄

F. Acker* and H. C. Ku

Institute for Pure and Applied Physical Sciences,† University of California—San Diego, La Jolla, California

(Received August 19, 1980)

Detailed measurements of the magnetization of HoRh₄B₄ and GdRh₄B₄ near the magnetic transition temperature are presented. In contrast to the ferromagnetic behavior of GdRh₄B₄, no spontaneous magnetization is found to develop below $T_m$ in HoRh₄B₄. This raises doubts about the nature of the magnetic order in that material as well as in DyRh₄B₄ and TbRh₄B₄. Anisotropy and time dependence of the magnetization are found in these last three compounds. The behavior of the very small remanent magnetization and of the paramagnetic susceptibility of HoRh₄B₄ is shown. These results point to a complex magnetic order, possibly helical or sinusoidal antiferromagnetism with a long wavelength.

1. INTRODUCTION

Magnetic ordering is found in all the CeCo₄B₄-type rare-earth (R) rhodium borides RRh₄B₄ except for LuRh₄B₄ (in the case of NdRh₄B₄ and TmRh₄B₄ further confirmation is still needed).¹⁻³ Superconductivity occurs in RRh₄B₄ for R = Nd, Sm, Er, Tm, and Lu and appears to coexist with antiferromagnetic order in SmRh₄B₄, while it is destroyed by the onset of magnetic order in ErRh₄B₄. For R = Gd, Tb, Dy, and Ho, no superconductivity is observed and the magnetic order is thought to be ferromagnetic. The variation of the transition temperature $T_m$ for these magnetic compounds deviates strongly from the behavior expected from the de Gennes curve; $T_m$ is maximum (~11 K) for DyRh₄B₄. Other interesting and somewhat intriguing features are to be found in two recent papers⁴,⁵ dealing with the magnetic behavior of HoRh₄B₄. (i) The magnetization in high fields is unexpectedly small⁵ ($M < 5 \mu_B/\text{Ho}$ for $H = 100 \text{kOe}$). (ii) Above $T \approx 50 \text{K}$ the inverse susceptibility follows closely a Curie-Weiss law with an effective moment $\mu_{\text{eff}} = 10.55\mu_B/\text{Ho}$ (the free ion value) and a negative intercept

*Partially supported by a grant from the Swiss National Science Foundation.
†Research in La Jolla supported by National Science Foundation Grant No. DMR77-08467.
\( \theta = -8 \text{ K}; \) below 50 K, there is a marked downward curvature of \( \chi^{-1}(T) \) and the magnetic transition is observed at 6.7 K.\(^5\) By contrast, there is practically no curvature in \( \chi^{-1}(T) \) for the sample used in Ref. 4, and \( \theta = +2 \text{ K}; \) again the data above 50 K follow nearly perfectly a Curie–Weiss law with \( \mu_{\text{eff}} = 10.5 \mu_B/\text{Ho}. \) (iii) The magnetic contribution \( C_M(T) \) of the specific heat below \( T_m \) has a beautiful mean-field-like shape.\(^4\)

These features prompted us to study the magnetic behavior of \( \text{HoRh}_4\text{B}_4 \) in more detail. We followed the suggestion made in Ref. 5 to check whether the ideal mean field behavior observed for the magnetic specific heat reflects in the magnetization around \( T_m \). Data for \( \text{GdRh}_4\text{B}_4 \) were also taken for comparison.

2. EXPERIMENTAL DETAILS

The samples were synthesized by arc-melting the high-purity elements under Ar and were annealed in sealed quartz tubes (five days at 1150°C, followed by two weeks at 900°C, under Ar). Magnetic measurements were taken, on spherical and/or needle-shaped samples, in a vibrating sample magnetometer (\( \nu = 22 \text{ Hz} \)), where the sample was held in thermal equilibrium with a large Cu block. The temperature of the sample was thus easily controlled within \( \Delta T < 10^{-2} \text{ K} \) near \( T_m \). Temperature measurements were done with a Ge resistance thermometer. Isothermal measurements of the magnetization were performed near \( T_m \) at temperature intervals of about 0.3 K, in fields between 0 and 13 kOe.

3. EXPERIMENTAL RESULTS

When the magnetic behavior of \( \text{HoRh}_4\text{B}_4 \) is compared with that of \( \text{GdRh}_4\text{B}_4 \), striking differences are found. Figure 1 shows the low-field data for spherical samples after correction for the demagnetization effect. \( \text{GdRh}_4\text{B}_4 \) behaves like a ferromagnet (\( T_m = 5.5 \text{ K} \)). The magnetization strongly depends on temperature and field; below \( T_m \) the initial susceptibility tends to infinity; at 1.61 K, the magnetization in a field of 150 Oe already reaches 50% of the expected saturation value of 7\( \mu_B/\text{Gd} \) and in 3 kOe the figure is 86% (not shown). By contrast, the initial susceptibility of a (zero-field-cooled) \( \text{HoRh}_4\text{B}_4 \) sample remains finite and appears to be independent of \( T \) below \( T_m \). This is even more apparent in an Arrott plot (\( M^2 \) vs. \( H/M \)) of the magnetization (Fig. 2). For \( T > T_m \) the magnetic isotherms in moderate fields (\( H < 2 \text{ kOe} \)) define a set of parallel straight lines which intersect the \( H/M \) axis at reliable values of the zero-field inverse susceptibility \( \chi_0^{-1}(T) \). Below 6.3 K the magnetic behavior is very peculiar. Instead of remaining parallel and cutting the \( M^2 \) axis at positive values