Splitting of the Néel transition in holmium in a magnetic field

M. O. Steinitz and M. Kahrizi
Department of Physics, St. Francis Xavier University, Antigonish, Nova Scotia, Canada B2G 1C0

D. A. Tindall
Department of Physics, Dalhousie University, Halifax, Nova Scotia, Canada B3H 3J5
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We report the first observation of a splitting of the Néel transition in holmium in an applied magnetic field. Such a splitting was predicted by Schaub and Mukamel for rare-earth metals with $n=4$ order parameters in a field normal to the spiral axis, so this observation may indicate the occurrence of the linearly polarized spin-density-wave phase which they suggested.

We have observed that the Néel transition in holmium splits into two transitions in a magnetic field applied along the a axis. This is consistent with the prediction of Schaub and Mukamel[1] for rare-earth metals with $n=4$ order parameters (Ho, Tb, Dy) that a field applied normal to the c axis (the spiral axis of the spiral phase found in $H=0$) should introduce a new linearly polarized spin-density-wave (SDW) phase between the paramagnetic phase and the spiral phase. This measurement does not confirm the existence of that phase, but does confirm the existence of a new phase, whose nature should be resolved by neutron diffraction studies. Studies with field applied along the c axis are in progress.

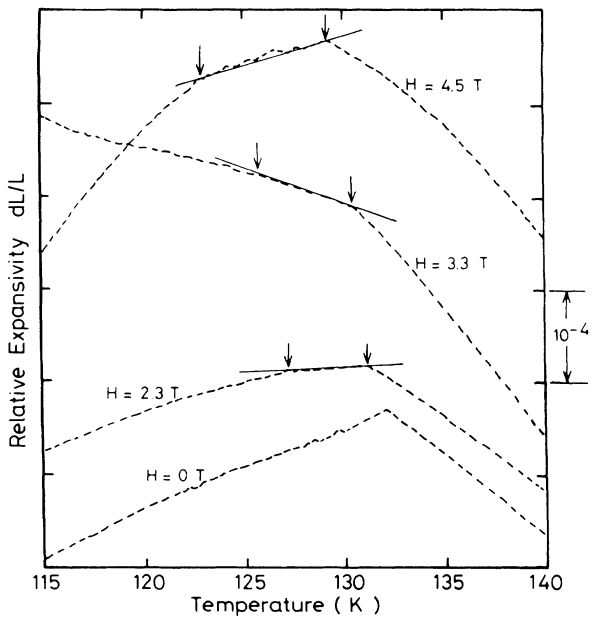

FIG. 1. Relative expansivity of holmium along the a axis relative to the dilatometer material vs temperature (uncorrected for field effects on the thermometer) in fields of 0, 2.3, 3.3, and 4.5 T. The curves have been vertically displaced by an arbitrary amount for visual clarity.

Using a sample of holmium provided by H. Astrom of the Royal Institute of Technology in Stockholm, Sweden, we undertook dilatometric measurements[2] along the a axis in varying fields applied along the same axis. Although calorimetric measurements on this sample showed a small first-order transition[3] at T_N, and detailed examination of our $H=0$ runs did show a small first-order effect at T_N, we did not observe the same first-order effects along the a axis in this sample that had been observed on a different sample in 1977.[4]

Temperature sweeps were made at a rate of roughly 1 K/min at constant field from 77 to 150 K in fields of 0, 2.3, 3.2, and 4.5 T. The curves shown in Fig. 1 clearly show a second transition T_2 moving away from T_N toward lower temperatures. The low-temperature behavior is quite complicated, as might be expected if one considers the variety of phases found below 77 K by Koehler *et al.*[5] Thus the changes in the thermal expansion coefficient

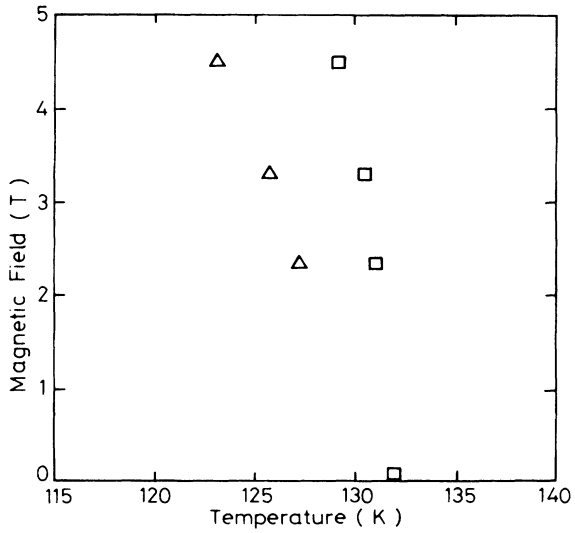

FIG. 2. Observed transition temperatures T_N (open squares) and T_2 (open triangles) (uncorrected for field-induced errors of about -1 K/T in the thermometer) vs applied magnetic field.

below the new transition as a function of field may reflect quite different magnetic phases. The temperatures were measured using a silicon diode thermometer, which has an absolute temperature error of about -1 K/T in this temperature range.

Figure 2 shows the field dependence of the observed temperatures without correction for the field effect on the thermometer. If one makes a rough correction for the effect of the field on the thermometer one can see that T_N is essentially independent of field, and that T_2 (the transition from the presumed SDW phase to the spiral phase) is weakly field dependent. Although both transitions appear to be continuous from examination of this data, further detailed work will be required to determine the first- or second-order nature of the transitions in the magnetic field.

It is interesting to note that no such splitting was observed by Tarvin and Eckert[6] who examined the temperature dependence of the (002) satellite from 115 K to above T_N in a field of 4 T applied along the $[1\bar{2}0]$ direction. This may be due to differences in sample purity although a kink may be observed in their data at about 127 K. Our sample had a residual resistance ratio (R) of about 80 and a value of $T_N = 132$ K in zero field compared to the value of 130.6 reported by Eckert and Shirane.[7] This may be significant in view of the qualitative differences between different samples of dysprosium observed by Zochowski *et al.*[8] who found differences in T_N of 1.3 K between samples of $R = 21$ and $R = 88$.

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