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Small-angle neutron scattering of $(Er_{0.8}Ho_{0.2})Rh_4B_4$

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The $(Er_{1-x}Ho_x)Rh_4B_4$ pseudoternary alloy system has a minimum in the phase boundary between the superconducting and ferromagnetic phases near $x = 0.3$. This minimum has been identified as due to the competing magnetic anisotropies of Er and Ho. It has also been suggested that there could be a Lifschitz point near the minimum. Using the 30-m SANS camera at the National Center for Small-Angle Scattering Research at ORNL, we have observed a peak in the SANS pattern for $(Er_{0.8}Ho_{0.2})Rh_4B_4$ at $Q = 0.065$ Å^{-1}. This peak appears for temperatures between T_{c2}, measured upon cooling, and T_m, and corresponds to a modulation of the magnetic moment with a wavelength of about 100 Å, demonstrating that the modulated moment phase exists away from the $ErRh_4B_4$ end of the phase diagram. The wavelength of the modulation is the same as was previously observed in $ErRh_4B_4$. The fact that the wavelength of the modulation remains finite near $x = 0.3$ appears to rule out the possibility of Lifschitz behavior near this point.

INTRODUCTION

The pseudoternary rare-earth (RE) rhodium boride compounds $RERh_4B_4$ are useful for studying the interaction between superconductivity and long-range magnetic order, as well as for exploring the effects of competing magnetic moment anisotropies and magnetic order. One example of a pseudoternary system is the $(Er_{1-x}Ho_x)Rh_4B_4$ system, whose low-temperature phase diagram[1] is shown in Fig. 1. The phase boundaries have been determined from ac magnetic susceptibility[2,3] and neutron diffraction measurements.[4,5]

The phase diagram displays regions in which the Er^{3+} and Ho^{3+} moments independently order ferromagnetically within the basal plane and along the tetragonal c axis, respectively, separated by a region where the magnetic phases are mixed. There is also a temperature region above T_{c2} in which the sinusoidally modulated phase in $ErRh_4B_4$ coexists with normal ferromagnetic domains. This inhomogeneous phase presumably persists within the shaded area in Fig. 1, as previously conjectured[1] from ac magnetic susceptibility and neutron diffraction measurements.

The $T_{c2}(x)$ phase boundary has a minimum near $x = 0.3$. It has been suggested that near $x = 0.3$ there could be a Lifschitz point[6] or a tetracritical point.[7] In order to verify the existence of the modulated phase away from $x = 0$ and to examine the possibility of a Lifschitz point near $x = 0.3$, we made small-angle neutron scattering (SANS) measurements on a polycrystalline $(Er_{0.8}Ho_{0.2})Rh_4B_4$ sample at temperatures between 1.36 and 0.49 K. We observed a peak in the SANS signal at about $Q = 0.065$ Å^{-1}, corresponding to a sinusoidal modulation of the magnetic moment with a wavelength of close to 100 Å. The existence of this peak demonstrates that the inhomogeneous phase persists at $x = 0.2$, consistent with the conjectured shaded region in Fig. 1, and the wavelength at $x = 0.2$ has not changed significantly from the $x = 0$ value.

EXPERIMENTAL DETAILS

The $(Er_{0.8}Ho_{0.2})Rh_4B_4$ sample was synthesized by arc-melting the RE tetraborides with Rh under high-purity argon, followed by annealing in a manner previously described.[4] This sample is the same sample that was investigated in Ref. 5. Boron enriched in ^{11}B was used to reduce absorption. The sample was mounted in a ^3He refrigerator having a low-temperature capability of about 0.4 K. The SANS data were taken on the 30-m SANS instrument at the National Center for Small-Angle Scattering Research at Oak Ridge using a sample to detector distance of 3.71 m, which gave a useful Q range from about 0.015 to 0.14 Å^{-1}. The neutron wavelength was 4.75 Å. The SANS spectra were all isotropic and were radially averaged prior to data

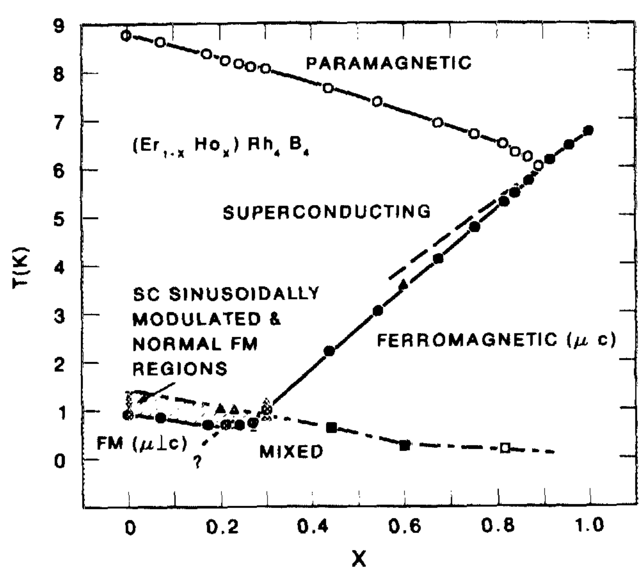

FIG. 1. Low-temperature phase diagram for the $(Er_{1-x}Ho_x)Rh_4B_4$ system.[1]

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analysis. All data were taken with the sample having been cooled from the superconducting phase.

RESULTS AND DISCUSSION

We measured SANS spectra at a number of temperatures between 1.36 and 0.49 K. For temperatures between about 1.0 and 0.5 K we observed peaks in the SANS patterns at Q values near 0.065 Å^{-1}. No peak was observed at 1.36 K. We corrected for instrumental background by subtracting the radially averaged 1.36-K data from the data for the other temperatures. The background corrected data were then fit to Gaussians plus additional sloping backgrounds. The corrected data and fits for five of the temperatures are shown in Fig. 2. A very weak peak showed up in an additional scan taken at 0.49 K., but the data are not plotted in this figure to avoid confusion with the rest of the data. The sloping background in Fig. 2, which becomes stronger as the temperature is lowered, is attributed to scattering from the ferromagnetic phase.

Table I shows the positions of the fitted Gaussians and the integrated intensities of the peaks, obtained from the difference between the observed data and fitted backgrounds. The integrated intensity of the small-angle peak as a function of temperature is plotted in Fig. 3. The modulated moment phase exists over a wider temperature range than in $ErRh_4B_4$, and coincides with the hysteresis observed in the magnetic intensity of the (101) reflection previously measured on the sample.[5] This was anticipated based on the wider thermal hysteresis in the ac susceptibility in $(Er_{0.73}Ho_{0.27})Rh_4B_4$ as compared to $ErRh_4B_4$.[3] These results show that the modulated moment phase persists to x-values close to the minimum in the $T_{c2}(x)$ phase boundary, where the

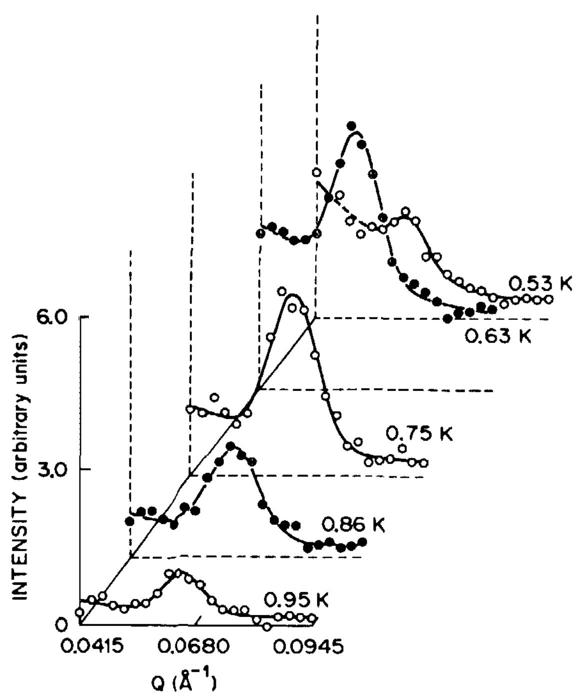

FIG. 2. SANS peak from $(Er_{0.8}Ho_{0.2})Rh_4B_4$ at various temperatures.

TABLE I. Fitted positions $(\text{Å})^{-1}$ and calculated integrated intensities (arbitrary units) of the SANS peaks from the sinusoidal modulation of the magnetic moment in $(Er_{0.8}Ho_{0.2})Rh_4B_4$.

T (K)	Peak position	Intensity
0.95	0.0652 ± 0.0009	0.0087 ± 0.0010
0.86	0.0654 ± 0.0009	0.0238 ± 0.0018
0.75	0.0646 ± 0.0007	0.0388 ± 0.0022
0.63	0.0632 ± 0.0005	0.0340 ± 0.0016
0.53	0.0628 ± 0.0013	0.0086 ± 0.0013
0.49	0.0627 ± 0.0015	0.0014 ± 0.0013

ferromagnetic alignment which destroys the superconducting state changes direction from within the basal plane to along the c axis,[8] and verify the existence of the shaded region of the low-temperature phase diagram in Fig. 1.

Figure 4 is a plot of the position of the peak as a function of temperature. The corresponding wavelengths range from 96.4 ± 1.4 Å at 0.95 K to 100.2 ± 2.5 Å at 0.49 K. There is little change in the wave vector of the modulation over the entire temperature range where the modulated moment phase exists, except for possibly a slight decrease at lower temperatures. This is in contrast to $ErRh_4B_4$, where a slight decrease in the wave vector of the modulation was observed at higher temperatures.[9]

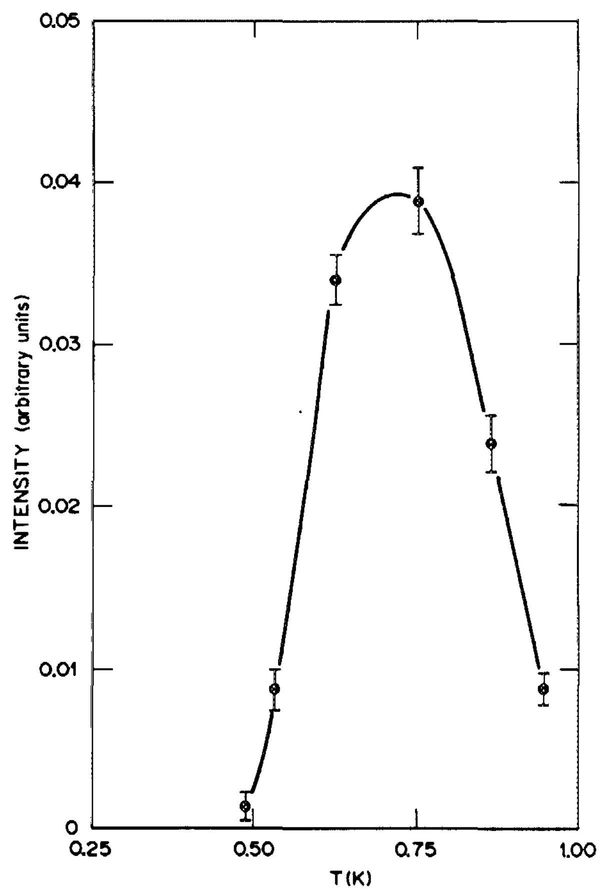

FIG. 3. Integrated intensity of the SANS peak as a function of temperature. The measured data were corrected for background prior to integration. The line connecting the points is a guide to the eye.

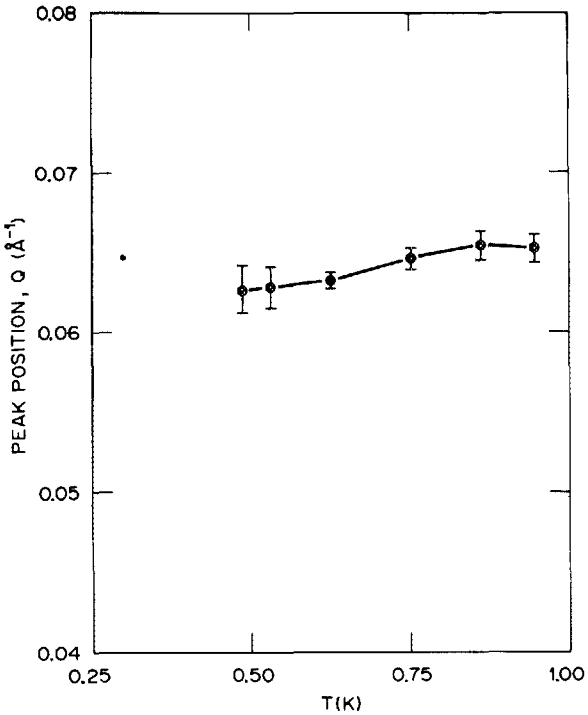

FIG. 4. Position of the SANS peak as a function of temperature. The positions were obtained from least-squares fits of Gaussians and sloping backgrounds to the data. The line connecting the points is a guide to the eye.

More significantly, the wavelength of the modulation has not changed appreciably from the $x = 0$ case (about 100 Å).[9,10] For a Lifschitz point to exist near $x = 0.3$, the magnitude of the wave vector of the modulation must approach zero continuously as x approaches 0.3. The fact that the wave vector remains the same at $x = 0.2$ as at $x = 0$ virtually rules out the existence of a Lifschitz point near $x = 0.3$

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