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**A CRITICAL SCATTERING STUDY OF THE
HELICAL ANTIFERROMAGNETS Ho AND Dy**

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We have measured the frequency integrated magnetic critical scattering of neutrons from paramagnetic Dy and Ho. Analysis of these data show the paramagnetic to helical antiferromagnetic phase transitions are characterized by the critical exponents $\nu = 0.57 \pm 0.05$ and $\gamma = 1.05 \pm .07$ for Dy and $\nu = 0.57 \pm .04$ and $\gamma = 1.14 \pm .10$ for Ho.

**Key Words: Phase Transitions, Neutron Scattering,
Rare Earth Metals**

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This paper reports on a neutron scattering study of the paramagnetic to helical magnetic phase transition in Dy and Ho. Specifically, we have measured the frequency integrated critical scattering of neutrons in the paramagnetic state for the purpose of determining the γ and ν critical exponents. The antiferromagnetic structure in the helical phase of these materials is known.[1] The magnetic moments lie within the basal, ab, plane and are strongly ferromagnetically coupled within this plane. Along the hexagonal c direction, however, the moments are rotated with respect to neighboring ab planes so as to form a helical or spiral structure along c.

Bak and Mukamel,[2] have argued that in this state the order parameter had four independent components, and used renormalization group techniques to calculate the exponents relevant to the phase transition. More recently Kawamura[3] has used an analogy between the "topological order parameter space" for the transitions in Dy and Ho and that of the transition of a three dimensional XY antiferromagnet on a layered triangular lattice, and has calculated values for the critical exponents using Monte Carlo techniques.

The neutron scattering measurements were performed on triple-axis spectrometers at Oak Ridge National Laboratory. The frequency integration of the critical scattering was achieved by removing the analyzing crystal. The measurements on the Ho crystal were made with the (H,H,L) plane of the crystal lying in the scattering plane. The measurements on the Dy crystal were performed using a sample grown from the lower neutron absorbing isotope ^{163}Dy . The (H,0,L) plane of this crystal lay in the scattering plane. The samples were mounted in a Displex refrigerator and all measurements were made with the temperature stable to at least 0.03 K.

Above the Neel temperature the critical scattering peaks at satellite wave vectors which appear at the positions $(0,0,\pm\tau)$ with respect to the nuclear Bragg peaks, where τ is the helical wave vector. Scans were performed through the nominal satellite position at $(0,0,2+\tau)$ both along $(0,0,L)$ and perpendicular to the $(0,0,L)$ axis through $(0,0,2+\tau)$, at various temperatures above the phase transitions.

We have fitted the measured critical scattering at each temperature to a fixed background plus the convolution integral of the instrumental resolution

function with a structure factor, $S(\bar{q})$, for the magnetic scattering given by:

$$S(\bar{q}) = \frac{\chi_A(T)}{1 + \left(\frac{q^c - \tau}{\kappa_A^c} \right)^2 + \left(\frac{q^{ab}}{\kappa_A^{ab}} \right)^2} + \frac{\chi_F(T)}{1 + \left(\frac{q^c}{\kappa_F^c} \right)^2 + \left(\frac{q^{ab}}{\kappa_F^{ab}} \right)^2} \quad (1)$$

where $\bar{q}$ was measured from the (0,0,2) zone center. The first term on the right hand side of Eq. 1 represents the antiferromagnetic critical scattering and the second term represents ferromagnetic scattering. While this ferromagnetic scattering was noncritical and always relatively weak, compared with the antiferromagnetic scattering, it was necessary for a satisfactory description of the data. In both Dy and Ho the critical scattering was anisotropic and therefore Eq. 1 contains two antiferromagnetic and ferromagnetic inverse correlation lengths. The amplitudes of the two components in Eq. 1, $\chi_A(T)$ and $\chi_F(T)$ represent the static antiferromagnetic and ferromagnetic susceptibilities, respectively.

The results of this fitting procedure provided an excellent description of the data. The relative importance of the ferromagnetic contribution to the

scattering was greater in Dy than in Ho. As both Dy and Ho undergo first order phase transitions at lower temperatures to magnetic structures with ferromagnetic components,[1] it is not surprising that some ferromagnetic scattering is seen.

The values for κ_A^c , κ_A^{ab} , and χ_A resulting from these fits were fitted to three power law functions of the reduced temperature $t = (T - T_N)/T_N$, and values for the critical exponents were deduced from these fits. The results of these fits to the data are shown in Figures 1 and 2. In the case of the Dy data, only those data points for temperatures below 191 K have been used to extract the critical behavior. The Neel temperatures determined by these fits were $T_N = 180.15 \pm .10$ K for Dy and $T_N = 132.19 \pm .05$ K for Ho.

In both Dy and Ho the critical exponents ν_c and ν_{ab} deduced from the inverse correlation lengths are to within experimental error the same. Consequently, we have averaged these values to get an overall value for ν in Dy and Ho. These average values and also the values for γ are summarized in Table 1, along with the theoretical values.

The conclusions which can be drawn from this comparison with theory are as follows. The critical

exponents, γ and ν , originally predicted for these systems by Bak and Mukamel are not appropriate. The prediction by Kawamura that Dy and Ho belong to a new universality class including the layered, triangular lattice XY antiferromagnet appears to be correct, and the predicted critical exponents agree well with the experimental values determined in this study.

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FIGURE CAPTIONS

Fig. 1. The staggered susceptibility, χ_A , is shown as a function of reduced temperature, $t = (T - T_N)/T_N$ for Dy (solid circles) and Ho (open circles). The lines drawn are fits to power law functions $\chi = \chi_0 t^{-\gamma}$.

Fig. 2. The antiferromagnetic inverse correlation lengths along c, κ_A^c , and within the ab plane, κ_A^{ab} , are shown as a function of reduced temperature, $t = (T - T_N)/T_N$ for Dy (solid circles) and Ho (open circles). The lines drawn are fits to power law functions $\kappa = \kappa_0 t^{\nu}$.

Table 1. The experimental values for the critical exponents ν and γ determined for Dy and Ho (this work) are compared with the theoretical values calculated by Bak and Mukamel[2] and by Kawamura[3].

	ν	γ
	Experiment	
Dy	0.57 ± 0.05	1.05 ± 0.07
Ho	0.57 ± 0.04	1.14 ± 0.10
	Theory	
Ref. 2	0.70	1.39
Ref. 3	0.53 ± 0.03	1.10 ± 0.10

Fig. 1

Fig. 2

Fig. 1

Fig. 2