

# Magnetic X-ray Scattering Study of $\text{GdCo}_2\text{Ge}_2$

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## Introduction

Factors that impact upon the magnetic ordering in rare-earth compounds such as  $\text{RCo}_2\text{Ge}_2$ , where R is the rare-earth element, include the Ruderman-Kittel-Kasuya-Yoshida (RKKY) interaction and the crystal electric field anisotropy. By interchanging the rare-earth ion, varying degrees of anisotropy develop, and crystalline electric fields (CEFs) become important.  $\text{NdCo}_2\text{Ge}_2$  and  $\text{DyCo}_2\text{Ge}_2$  are two examples of compounds that possess a high degree of anisotropy and could be candidates for detailed spin glass studies. In order to study the anisotropy and CEF, it is necessary to start with a control compound that exemplifies the magnetic state in the absence of these factors. Gd ions have negligible single ion anisotropy, and their energy levels have no exchange splitting because of the half-filled 4f shell. This makes  $\text{GdCo}_2\text{Ge}_2$  the best candidate to study magnetic ordering in the absence of CEF effects. It is necessary to determine the wave vector and moment direction for  $\text{GdCo}_2\text{Ge}_2$  to provide a starting point for defining the collective behavior of the magnetic moments in the series.

## Methods and Materials

Each compound of the series  $\text{RCo}_2\text{Ge}_2$  has a tetragonal  $\text{ThCr}_2\text{Si}_2$ -type structure (space group  $I4/mmm$ ). Single crystals were grown at Ames Laboratory by using a high-temperature-flux growth technique [1]. The crystals form as platelets, with the unique c-axis perpendicular to the surface. The experiment was carried out at the Midwest Universities Collaborative Access Team (MU-CAT) sector 6-ID beamline at the APS. A liquid-nitrogen-cooled, double-bounce Si(111) monochromator and a bent mirror were used to select an energy, focus the beam, and suppress higher-order harmonics. The sample was mounted on a copper rod in the cold finger of a Displex closed-cycle cryostat. The sample, oriented so that the scattering plane was coincident with the  $(h0l)$  zone, was encapsulated in a Be dome with a He exchange gas to enhance thermal stabilization.

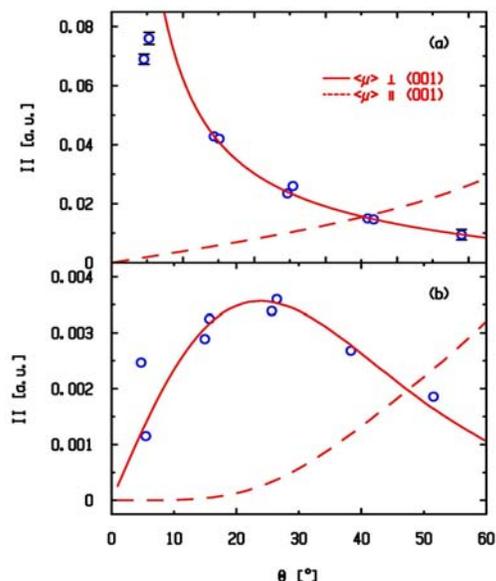


FIG. 1. Plot (a) shows the resonant integrated intensity measurement at the Gd  $L_{III}$  edge. Plot (b) shows the same measurement performed 250 eV below the edge to study the nonresonant scattering. In both plots, the solid line represents moments perpendicular to the c-axis, and the dashed line represents moments parallel to c.

## Results

The compound  $\text{GdCo}_2\text{Ge}_2$  orders antiferromagnetically below a transition temperature of  $T_N = 32.9\text{K} \pm 0.2$ . The modulation wave vector was found to be incommensurate and have the value  $(0\ 0\ k_z)$  where  $k_z = 0.931 \pm 0.001$  reciprocal lattice unit (rlu).

A comparison of the  $Q$ -dependent integrated intensity with the theoretical cross section for a dipole resonant process shows that the moments are oriented perpendicular to the c-axis, as shown in Fig. 1(a). The nonresonant measurement also confirms that the moments are in the tetragonal basal plane of the sample, as shown in Fig. 1(b).

## Discussion

A careful study of the other rare-earths in the series will illuminate the role that each interaction plays in the magnetic ordering. Though neutron studies have been

performed on some of the compounds [2], the higher resolution of the x-ray technique will be essential to fully determine the ordering of the magnetic state in the series.

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### **References**

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