Critical Magnetic Behavior of the Antiferromagnetic Component in the Ferromagnet GdMg

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Introduction

GdMg shows very clearly the typical phenomena induced by fourth-order exchange interactions, i.e., biquadratic, three-spin and four-spin interactions. At $T_C = 110$ K GdMg orders ferromagnetically, but the saturation magnetic moment reaches only ~$5.2\mu_B$ instead of $7\mu_B$ expected for the Gd atom.[2] The deviation of the spontaneous magnetization from saturation at absolute zero is perfectly described by a single T^2 power term. Surprisingly, the critical magnetic behaviour is mean-field-like at the Curie temperature of 110 K.[1] Both features fit not the Heisenberg model of ferromagnetism and are considered as typical signatures of fourth-order exchange interactions.

At $T_N = 91$ K the magnetic specific heat exhibits a sharp absolute maximum.[1] Below this temperature, an antiferromagnetic order occurs in addition to the persisting ferromagnetic order. Interestingly, the ferromagnetic order parameter shows virtually no anomaly at T_N. The antiferromagnetic component also reaches a saturation value of ~$5\mu_B$. The two ordered structures are perpendicular to each other and their saturation moments add geometrically to the full Gd moment. We identify the antiferromagnetic component with the order parameter O_4 induced exclusively by fourth-order exchange interactions. Evidence for the existence of these interactions is provided by the cubic susceptibility χ_3 which diverges at T_N.[1] The aim of the present experiment is to evaluate the temperature dependence of O4.

Materials and Methods

All measurements are carried out on a polished (1,0,0) surface of an oriented GdMg single crystal using station B of beamline 06-ID of MUCAT. To profit from resonance-enhanced magnetic scattering, the incoming energy is set to the Gd L_{II} absorption edge at an energy of 7.932 keV (~0.138 Angstrom).

Results

The temperature dependence of the normalized square root of the integrated 0,0,5/2 magnetic scattering intensity (order parameter O_4) is shown as a function of T_2 in Fig.1. Alternative plots vs. $T_{1.5}$ or $T_{2.5}$ would result in the indicated curved behaviour. It can be seen that the T_2 fit holds excellently up to 0.8 of the critical temperature of $T_N = 91$ K. The same temperature dependence was observed for the conventional ferromagnetic order parameter (O_2) using macroscopic magnetization measurements.[1]

Figure 2 gives a comparative view of the critical behavior of the macroscopic magnetization (order parameter O_2) and the antiferromagnetic order parameter O_4. The Néel temperature of O_4 is well known from the peak position of the magnetic specific heat and from the divergence of χ_3.[1] In the critical temperature range, the sublattice magnetization, i.e., the order parameter O_4, can be fitted by a discontinuous rise of $1.5\mu_B$ at $T_N = 90.5$ K and a consecutive power law with a critical exponent $\beta = 0.5$. As at the Curie transition at $T_C = 110$ K the critical exponent β is mean-field-like, but in contrast to the Curie transition at T_C, the phase

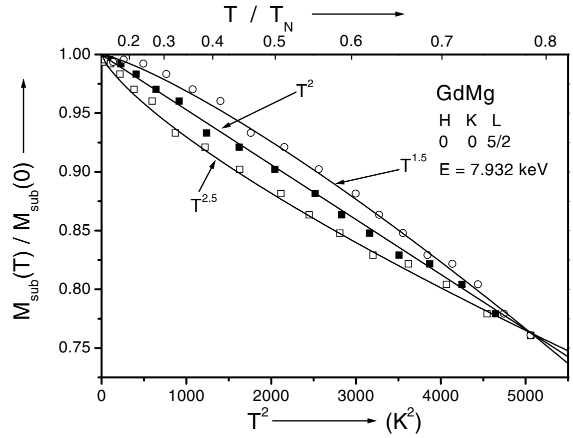

FIG. 1. Normalized square root of antiferromagnetic 0,0,5/2 scattering intensity (sublattice magnetization) vs. T_2. In alternative plots vs. $T_{1.5}$ or $T_{2.5}$, a curved behavior would result, as is indicated.

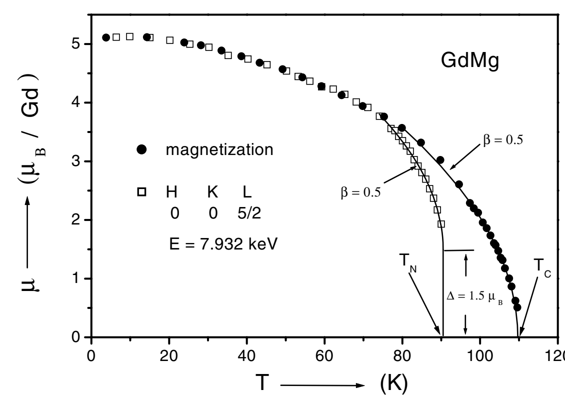

FIG. 2. Comparison between macroscopic spontaneous magnetization (O_2) and antiferromagnetic component (O_4). Solid lines are power law fits with mean field critical exponent $\beta = 0.5$.

transition at $T_N = 90.5$ K is clearly first order. This we expect for a phase transition driven by fourth-order exchange interactions. Critical diffuse scattering seems to be very weak below T_N.

Discussion

The antiferromagnetic structure in GdMg is identified as the order parameter O_4 induced by fourth-order exchange interactions. This experiment has shown that both order parameters exhibit a T_2 spin wave law and the mean field critical exponent $\beta = 0.5$. Both features are considered as characteristic for materials with isotropic interactions and half-integral spin quantum number.

Acknowledgments

The Midwest Universities Collaborative Access Team (MUCAT) sector at the Advanced Photon Source (APS) is supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, through the Ames Laboratory under Contract No. W-7405-ENG-82.

Use of the APS was supported by the U.S. Department of Energy, Office of Science, Basic Energy Sciences, under Contract No. W-31-109-ENG-38.

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