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 \(-5\mu_B\) 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.\(^3\) 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 \( \chi_3 \) which diverges at \( T_N \).\(^4\) The aim of the present experiment is to evaluate the temperature dependence of \( O_4 \).

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 beam-line 06-ID of MUCAT. To profit from resonance-enhanced magnetic scattering, the incoming energy is set to the Gd LII 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 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.

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References