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From antiferromagnetic order to a field-polarised state in the heavy-fermion compound YbAgGe

P.G. Niklowitz [a,*,1], C. Paulsen [b]

[a] *Département de Recherche Fondamentale sur la Matière Condensée, SPSMS, CEA Grenoble, 38054 Grenoble Cedex 9, France*
[b] *Centre de Recherche sur les Très Basses Températures, CNRS, BP 166, 38042 Grenoble Cedex 9, France*

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Abstract

Magnetisation measurements between 75 mK and 1 K were used to study the evolution up to magnetic fields of 8 T of the magnetic properties of the heavy-fermion metal YbAgGe. The magnetisation data confirms a first-order transition between two antiferromagnetic states, which is suppressed at 2 T. Close to 5 T, which is a field region where the known antiferromagnetic long-range order is already suppressed, the static linear susceptibility is enhanced, accompanied by a strong increase of the linear specific-heat coefficient. However, the enhancement of the static linear susceptibility is not strong enough to be alone responsible for the strong increase of the quasi-linear resistivity observed previously.

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1. Introduction

YbAgGe offers a new possibility for the study of enhanced fluctuations around a field induced magnetic quantum phase transition in a stoichiometric compound. YbAgGe has recently been recognised as a new heavy-fermion system with a linear specific heat coefficient γ of a few hundred $\mathrm{mJ/mol\,K^2}$ at low temperatures and a Kondo temperature $T_\mathrm{K} \approx 25$ K [1,2]. YbAgGe orders in the hexagonal ZrNiAl-type structure [1]. The Yb^{3+} ions are exposed to a crystal field with an orthorhombic point symmetry, which splits their eight-fold $J = 7/2$ multiplet into four doublets. The only crystal-field excitation detected up to now sits at 12 meV. However it is uncertain, whether this represents the lowest-lying crystal-field excitation [2,3]. YbAgGe has a low-temperature magnetic anisotropy $\chi_{ab}/\chi_c \approx 3$ [1,2]. Saturation of the magnetisation close to 15 T is only found when the field is applied in the easy plane. Above T_K the susceptibility derived from the magnetisation data follows the Curie–Weiss law with an effective moment of $4.4\mu_\mathrm{B}$ (close to the free-ion value for Yb^{3+}) and with a Weiss temperature $\Theta = -30$ K, which suggests antiferromagnetic interactions between the moments [1,2]. Two antiferromagnetic phases have indeed been found below $T_1 = 0.65$ K (AF1, commensurate) and below $T_2 = 0.9 \pm 0.1$ K (AF2, incommensurate) [1,4–7]. The transition between the two antiferromagnetic phases is first order [1,4,5]. Neutron scattering measurements suggest that the suppression of the AF2 phase at T_2 is second-order [7]. Inelastic neutron scattering at the AF1 ordering wave vector was found to be quasielastic, but showed the temperature dependence characteristic of a heavy-fermion material only at higher temperatures [6]. Below 15 K the temperature dependence is stronger in parts of reciprocal space. A resulting anomalous $\mathbf{q}$-dependence of the linewidth $\Gamma(\mathbf{q})$ at low temperatures might originate from frustration effects in the Kagome lattice of the Yb-ions in the basal plane [6].

Upon the application of a magnetic field the two magnetically ordered phases become suppressed in the experimentally

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[*] Corresponding author.
E-mail address: philipp.niklowitz@frm2.tum.de (P.G. Niklowitz).

[1] Present address: Physik Department E21, Technische Universität München, James-Franck-Str., 85747 Garching, Germany.

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well accessible range of less than 10 T and non-Fermi-liquid (NFL) behaviour is induced in the heat capacity and in the electrical resistivity [4,8]. If the field is applied in the basal plane, the previously found critical fields are $H_{c1} = 1.9$ T and $H_{c2} = 3.0$ T, respectively [7]. Apart from neutron scattering the suppression of the AF2 phase has only been observed in the magnetoresistance [8]. However, the suppression of the AF1 phase can also be seen in transport, heat capacity, and magnetisation measurements [4,5,8]. In these measurements indications for a further transition at $H_{c3} = 4.9$ T are found. At this field NFL behaviour is induced, including a strongly enhanced temperature dependence of the resistivity [8]. H_{c3} is also the origin for a line defined by signatures in the Hall resistivity [9,10].

In this Letter we investigate the magnetisation of YbAgGe at low temperatures up to 8 T. Temperature sweeps from 75 mK up to 1 K and a field sweep at 100 mK have been performed. The magnetic phase diagram is reinvestigated and information on the nature of the phase transition at H_{c3} is collected. This includes a derivation from the magnetisation data of the field and temperature dependence of the static linear susceptibility.

2. Experimental

YbAgGe samples in form of several mm long rods with clean hexagonal cross section of about 0.5 mm^2 were grown from high-temperature ternary solutions rich in Ag and Ge [1]. Magnetisation measurements on a sample of 7.1 mg were performed using a SQUID-magnetometer. The measurements were done in a dilution refrigerator, inserted in an 8 T superconducting magnet.

3. Results

In Fig. 1 we show the set of temperature sweeps of the magnetisation of YbAgGe at different fields. The clear step-like increase of M in the low-field curves (Fig. 1a) marks the first-order transition T_1 between the two antiferromagnetically ordered phases AF1 and AF2. The field dependence of T_1 agrees well with the phase diagram of YbAgGe obtained from previous thermodynamic, transport, and neutron measurements. No signature of the suppresion of the AF2 phase (T_2) is found in the magnetisation data. However, close to the transition or crossover at H_{c3}, whose nature had not been revealed up to now, a regime change is observed in the temperature dependence of M. While $M(T)$ below 5 T is rising at low temperatures, it is falling at and above 5 T (Figs. 1b and 1c). The inset in Fig. 1c visualises that at high fields $M(T)$ has a quadratic temperature dependence with negative coefficient over at least an order of magnitude in temperature. The size of the ordered moment of YbAgGe at 8 T in these measurements ($1.2\mu_B$) is close to the observed moment in previous magnetisation measurements at 2 K and 450 mK [1,4,5]. The results also compare well with an independent very recent low temperature measurement [11].

The low-temperature field dependence (Fig. 2) of the magnetisation also shows a signature close to H_{c3}, where it rises more steeply. A qualitatively similar feature has already been observed in neutron scattering experiments, in which the field

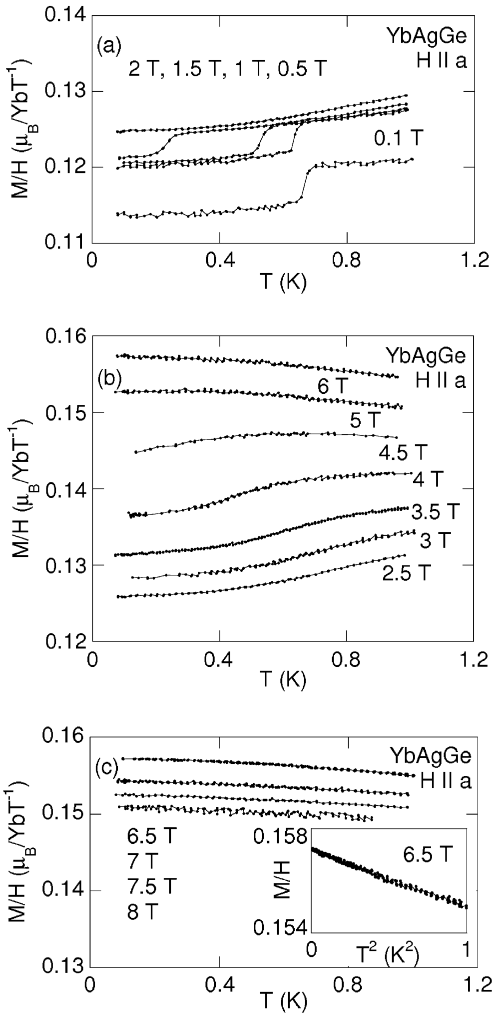

Fig. 1. Temperature dependence of the magnetisation for different fields. The low-field region shows the first-order transition between the AF1 and AF2 phase. There the measurements have been done after zero-field cooling. For clarity, the curves have been scaled by H.

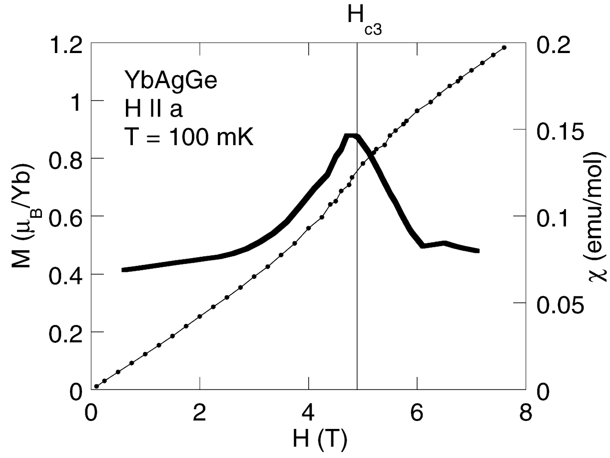

Fig. 2. Low-temperature field dependence of the magnetisation. Measurements have been performed after zero-field cooling. The static linear susceptibility is derived from the field sweep of the magnetisation.