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High field magnetisation measurements on UIr in the ferromagnetic state

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Abstract

We have performed high field magnetisation measurements on the ferromagnetic order ($T_C = 46\,K$) in single-crystalline UIr. The magnetisation along the easy axis shows a field saturation towards a moment of about $1\,\mu_B$/U atom at $T = 4.2\,K$. No field-induced magnetic transition was observed for magnetic fields up to 52 T.

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Keywords: UIr; High field magnetisation; Ferromagnetic order; Electron correlation

1. Introduction

The discovery of superconductivity in UGe_2 [1] provided an unanticipated example of coexistence of superconductivity and ferromagnetism. Coexistence of the two phenomena was later found at ambient pressure in URhGe [2]. Recently, superconductivity ($T_c = 0.14\,K$) was also found in ferromagnetically ordered UIr [3,4] in the vicinity of the critical pressure of 26–27 kbar, where the Curie temperature T_C is tuned to zero. With the coexistence of ferromagnetism and superconductivity, UIr belongs to a class of materials, which exhibit unconventional ground-state properties close to a quantum critical point. In this class of materials, UIr holds a special place because it is the only system where the crystal structure lacks inversion symmetry.

UIr crystallises in the monoclinic PbBi-type structure (space group $P2_1$) without inversion symmetry. The unit cell, with dimensions $a = 5.62\,\text{Å}$, $b = 10.59\,\text{Å}$, and $c = 5.60\,\text{Å}$ ($\alpha = 90^\circ$, $\beta = 98.9^\circ$, $\gamma = 90^\circ$) contains eight formula units with four inequivalent U and Ir sites [5]. UIr is an itinerant ferromagnet with a Curie temperature of $T_C = 46\,K$ at ambient pressure. Magnetisation measurements on a single crystal [6] up to 7 T revealed that the easy axis is parallel to $[1\,0\,\bar{1}]$, whereas the anisotropy with the hard axes [1 0 1] and [0 1 0] is large. Along the easy direction, the average saturated moment is equal to $0.5\,\mu_B$/U atom. The low-temperature coefficient of the linear electronic specific heat $\gamma = 48.5\,mJ/mol\,K^2$ [7] and the de Haas–van Alphen oscillations in the magnetisation [8] indicate a moderate enhancement of the electron correlations at ambient pressure. Magnetisation and electrical-resistivity measurements under pressure [3,4] showed that T_C is continuously suppressed for increasing pressures until the magnetic structure collapses at a pressure of about 17 kbar into a new ferromagnetic structure with a higher T_C. For even higher pressures, the ferromagnetic order is finally suppressed at a critical pressure of about 27 kbar.

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2. Experimental

A single-crystalline sample of UIr was grown by the Czochralski technique in a tri-arc furnace. No subsequent heat treatment was applied to the crystal. From this crystal, a sample with dimensions $1 \times 1 \times 1\,\mathrm{mm}^3$ and a mass of 13.2 mg was cut along the $[1\,0\,\bar{1}]$, [1 0 1], and [0 1 0] axis of the monoclinic crystal structure. High field magnetisation measurements up to a field of 52 T were performed at the pulsed field facility LNCMP in Toulouse. Initial tests were performed in continuous magnetic fields up to 30 T at the magnet facility HFML in Nijmegen.

3. Results and discussion

In Fig. 1 the high field magnetisation in UIr is shown at a temperature of $T = 4.2\,\mathrm{K}$ for pulsed magnetic fields along the $[1\,0\,\bar{1}]$, [1 0 1], and [0 1 0] direction. In agreement with the low field magnetisation measurements in fields up to 7 T [6], a linear increase in the magnetisation is observed for the [0 1 0] direction and a weak spin rotation followed by a linear increase in the magnetisation for the [1 0 1] direction. Along the $[1\,0\,\bar{1}]$ direction, which is the easy axis for the magnetisation, a sharp increase in magnetisation is observed in low applied magnetic fields. This jump in magnetisation of $0.5\,\mu_B$/U atom is caused by a repopulation of the ferromagnetic domains. For increasing magnetic fields, the magnetisation slowly increases. Up to the maximum applied field of 52 T no field-induced magnetic transition, related to a quenching of the magnetic interactions, is observed. The field dependence of the magnetisation $M(H)$ is accurately described by an empirical function of the form:

$$M(H) = M(0) + \Delta M\left(1 - \mathrm{e}^{-\mu_0 \mathrm{H}/\mathrm{B}_0}\right) \quad (1)$$

with $M(0) = 0.5101(2)\,\mu_B$/U atom, $\Delta M = 0.440(1)\,\mu_B$/U atom, and $B_0 = 42.6(2)\,\mathrm{T}$. The estimated high field moment $M(H = \infty) = M(0) + \Delta M \approx 1\,\mu_B$/U atom is significantly smaller than the free uranium $5f^2$ ($3.58\,\mu_B$) or $5f^3$ ($3.62\,\mu_B$) moments. High-temperature susceptibility measurements on polycrystalline samples [5] showed Curie–Weiss behaviour for temperatures between room temperature and 1200 K with an effective moment of $3.61\,\mu_B$/U atom and an unusually large antiferromagnetic Curie–Weiss temperature of $\theta_p = -430\,\mathrm{K}$. High-temperature magnetisation measurements on a single crystal [6] indicated an effective moment of $3.57\,\mu_B$/U atom and antiferromagnetic Curie–Weiss temperatures ranging from -300 to $-1000\,\mathrm{K}$ depending on the orientation. The deviations from the Curie–Weiss behaviour observed below a temperature of about 500 K signals a significant level splitting caused by crystalline electric field effects, which is responsible for the strong magnetocrystalline anisotropy. The crystalline electric field effects are probably also partly responsible for the reduced ordered moment observed for fields up to 52 T.

The interaction field $B_0 = 42.6(2)\,\mathrm{T}$, characteristic for the increase in magnetisation along the easy axis, probes the magnetic interaction strength of the applied magnetic field with the fluctuating itinerant moments. The corresponding interaction energy is of the order of $MB_0/k_B \approx 20\,\mathrm{K}$ for $M = 0.5$–$0.8\,\mu_B$/U atom.

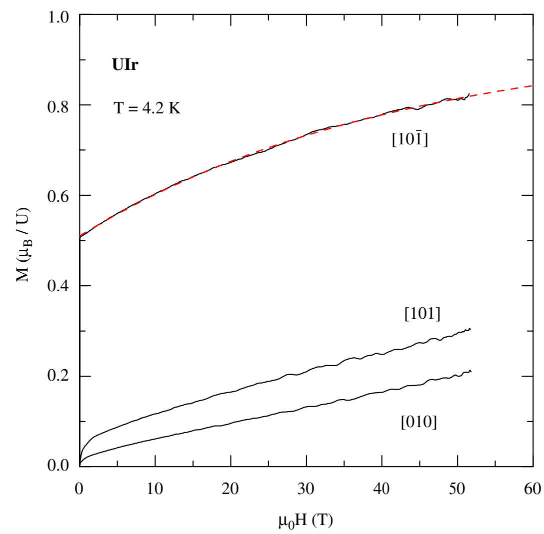

Fig. 1. High-field magnetisation M of single-crystalline UIr in pulsed magnetic fields $\mu_0 H$ along the $[1\,0\,\bar{1}]$, [1 0 1], and [0 1 0] axis. The dashed line indicates a fit to Eq. (1).

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