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ANOMALOUS MAGNETIC PROPERTIES OF URuGa*

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We present data of the magnetic susceptibility $\chi(T)$ and electrical resistivity $\rho(T)$ for the hexagonal URuGa (space group $P\bar{6}2m$). Below 7 K, χ increases rapidly and the data can be described by the expression $\chi(T) = \chi(0)\left(1 - a\sqrt{T}\right)$. $\rho(T)$ in zero field follows the activated form: $\rho(T) \sim \exp\left(E_a/2k_BT\right)$ with $E_a = 1.9$ meV. In an applied magnetic field of 1 T, the resistivity varies as $\rho(T) \sim bT$. Between 18 and 250 K the resistivity is linear in $-\ln T$ and consistent with a Kondo-like effect.

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1. Introduction

The existence of intermetallic URuGa was reported for the first time by Dwight [1]. The compound crystallizes in the hexagonal Fe_2P-type structure (space group $P\bar{6}2m$), which is a common structure adopted by most of U-based ternaries like: UTAl, UTGa, UTIn and UTSn (T is a d-electron transition metal) [1–8].

Previously, the physical properties of URuGa have been investigated by Havela et al. [7] and Sechovsky et al. [2, 8, 9]. The anomaly visible on the temperature dependences of both the lattice parameters and in the $\chi(T)$-curve at low temperatures led the authors of Ref. [7] to suggest that URuGa is a valence-fluctuation compound. This paper reports the magnetic susceptibility $\chi(T)$ and electrical resistivity $\rho(T)$ measured for polycrystalline URuGa. This investigation is part of a wider study of the system $URu_{1-x}Pd_xGa$ [10]. We observed a somewhat different magnetic behaviour of URuGa than that reported in Refs. [2] and [7]. We will discuss this difference below.

2. Experimental results and analysis

The polycrystalline sample of URuGa was prepared by arc-melting of stoichiometric amounts of the metals in a pure argon atmosphere. The obtained lattice parameters: $a = 7.098(1)$ Å and $c = 3.832(1)$ Å, compared with those reported

*Dedicated to Professor Wojciech Suski on the occasion of his 60th birthday.

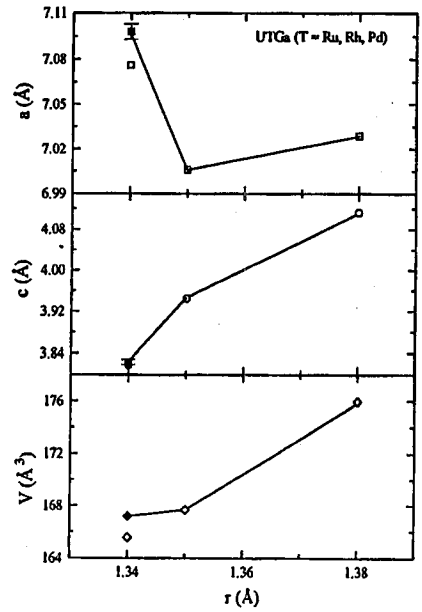


Fig. 1. Crystallographic parameters of UTGa (T = Ru, Rh and Pd) as a function of atomic radius of the transition-metal atoms. Open points are reference data [1, 7, 11].

previously for the intermetallics UTGa (T = Ru, Rh and Pd) [3, 11] show an evident deviation from those expected on the basis of the T-atomic-radius dependence of the lattice parameters (Fig. 1). This implies that U in URuGa may possess a different valence than that in URhGa or in UPdGa.

Between 100 and 300 K, the χ^{-1} vs. T plot is not linear, and thus the data were fitted to a modified Curie–Weiss (MCW) law (Fig. 2). Values of χ_0, μ_{eff} and θ_{p} are 0.8×10^{-3} emu/mole, 1.72 μ_{B}/at. U and 135 K, respectively. A distinct deviation of $\chi(T)$ from the high-temperature MCW behaviour becomes apparent below 75 K, followed by a rapid upturn below 7 K. Our data of the magnetic susceptibility taken down to 1.7 K are well described by the equation

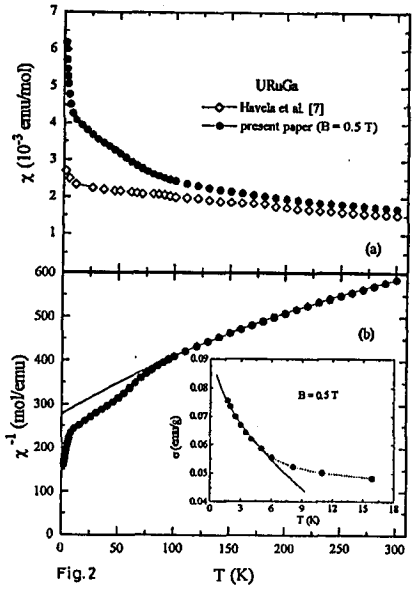
$$\chi(T) = \chi(0)(1 - a\sqrt{T}) \tag{1}$$

with $\chi(0) = 8.04 \times 10^{-3}$ emu/mole and $a = 0.182$ K$^{-1/2}$. Such an asymptotic dependence of the susceptibility has been observed in a new class of f-electron materials displaying a non-Fermi liquid (NFL) behaviour at low temperatures [12].

In contrast to the results of Havela et al. [7], we did not observe a broad maximum reported by these authors at about 80 K in $\rho(T)$, which often characterizes a valence fluctuation system (Fig. 3). In our measurements $\rho(T)$ is linear in $-\ln T$ over a rather wide range of temperatures, i.e. between 15 and 220 K, indicating a Kondo-like behaviour of this compound. Below 7 K, the resistivity (in zero field) increases according to the activated energy law

$$\rho(T) \sim \exp(E_a/2k_{\text{B}}T) \tag{2}$$

with $E_a = 1.9$ meV. This behaviour resembles that reported for CeNiSn [13, 14] or CeRhSb [15, 16]. In the latter cases, the phenomenon has been interpreted as



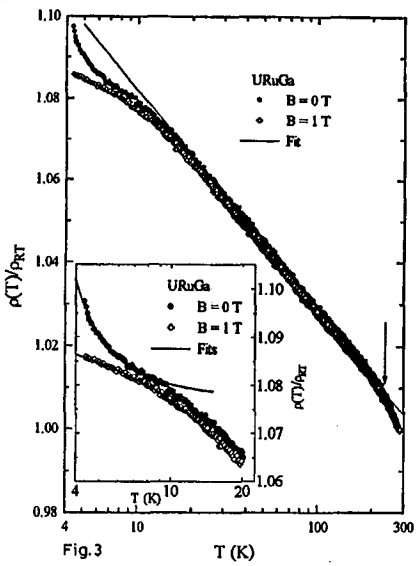


Fig. 2. (a) Temperature dependences of the magnetic susceptibility, measured by us and by Havela et al. [7]. (b) Temperature dependence of the reciprocal magnetic susceptibility. The solid line represents the fit to the MCW law. Inset: the solid line represents the fit of the magnetization data (points) to Eq. (1) (see the text).
Fig. 3 The reduced electrical resistivity $\rho(T)/\rho(300\ \mathrm{K})$, as a function of temperature measured in zero and 1 T. The solid line represents a $-\ln T$ dependence. Inset: the solid lines represent the fits of the resistivity data to Eqs. (2) and (3).

a result of the hybridization gap-formation in the electronic density of states. The effect of the magnetic field on the temperature dependence of the resistivity of URuGa is clearly observed at low temperatures (inset of Fig. 3). This leads the resistivity to vary linearly with decreasing temperature

$$\rho(T) = c + dT \tag{3}$$

where $c = 872.0\ \mu\Omega$ cm and $d = -1.2\ \mu\Omega$ cm/K. Such a negative temperature dependence of the resistivity may reflect the behaviour of the NFL-type compounds (see Ref. [12]), but measured in zero magnetic field.

In summary, it is clear that our data for polycrystalline URuGa have a number of similarities to the valence-fluctuating Kondo insulators [13–16] as well as to the non-Fermi liquid compounds [12], so that there is a possibility of the Kondo-effect behaviour at high temperatures and non-Fermi liquid one or/and the gap-formation at low temperatures. We do not exclude the presence of ferromagnetic (paramagnetic) impurities or a sign of forming the magnetic-correlation effect at low temperatures, which in turn becomes enhanced rapidly by even small substitution of Pd for Ru in URuGa [10]. We can classify the observed difference in the properties of URuGa as a quantitative shift in the magnetic and transport properties from the Kondo lattice behaviour (our data) towards fluctuating va-

lence character (Ref. [7] data). Hence, it seems that the samples measured by us and Havela et al. [7] reflect some small differences in purity and stoichiometry, which are however enough to influence largely their magnetic and transport properties. This finding is also in accordance with the larger unit cell volume of our URuGa compound (less hybridization effect).

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