THERMAL EXPANSION OF POLYCRYSTALLINE UPt₂, UPt₃ AND UPt₅

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The thermal expansion of the polycrystalline compounds UPt₂, UPt₃ and UPt₅ was measured in the temperature range 1.4 up to 80 K. Of particular interest is the spin-fluctuation compound UPt₃, which, after recently being discovered to behave as a heavy-fermion superconductor, nowadays receives much attention. Its thermal expansion reveals a large anomalous contribution below 50 K. This contribution appears as a low-temperature upturn in a plot of α/α² versus θ, and is associated with spin fluctuations. In the compounds UPt₂ and UPt₅ a similar upturn appears, although less pronounced. The thermal expansion data are compared with previously published specific heat data on the same samples.

The uranium-platinum system offers the possibility to study the competition between itinerant and local behaviour of the 5f electrons in uranium intermetallics. Along this series the U-U distance varies from 3.65 Å in orthorhombic UPt, 3.81 Å in orthorhombic UPt₂, 4.13 Å in hexagonal UPt₃, to 5.25 Å in cubic UPt₅, thus leading to a considerable decrease in overlap of the 5f orbitals.

Of particular interest is the compound UPt₃, which exhibits unusual low-temperature properties in the magnetic susceptibility and magnetization [1], in the specific heat [1, 2] and in the electrical resistivity [3], that could properly be described in a spin-fluctuation model. Moreover the recent discovery of superconductivity (Tₛ = 0.5 K) [4], and the classification of UPt₃ as a heavy fermion system with an effective mass m ≈ 180m₀ [2], has attracted much attention to this compound. In UPt₂ and UPt₅ spin-fluctuation effects are less pronounced.

In this paper we present thermal expansion measurements in the temperature range 1.4–80 K on the compounds UPt₂, UPt₃ and UPt₅. The experimental data are compared with previously published specific heat measurements on the same samples [1, 5], except for UPt₂. The thermal expansion of equiatomic UPt was recently studied by Kamma et al. [6].

The polycrystalline compounds were prepared by arc melting the appropriate amounts of constituents in a titanium gettered argon atmosphere. After casting of the melt into a water-cooled copper crucible, cylindrical samples were obtained with a diameter of 6 mm and a length of 10 mm. The as-cast samples were annealed in evacuated sealed silica tubes at 1000°C for a period of 10 days. Finally, all samples were machined by means of spark erosion into the proper shape: i.e. planparallel and with a hole of 2 mm diameter along the cylinder axis.

For the thermal expansion measurements a sensitive three-terminal capacitance method was used, with a detection limit for changes in length of 0.1 Å. A detailed description of the thermal expansion cell was given by Hölscher in his thesis [7]. Data were gathered stepwise: below 15 K each temperature step (0.3 K) was made three times, i.e. up, down and up again, whereas above 15 K only steps upwards (mounting up to 3 K) were made. The accuracy in the results decreased with increasing temperature due to small temperature gradients over the cell, and is limited to 2 × 10⁻⁷ K⁻¹ in α near 80 K.

The experimental results, obtained within several runs, are presented in fig. 1 as α = 1/L(dL/dT) versus T. Relative length changes, ΔL/L, were deduced by integration, see fig. 2.

The overall picture displays a rather large thermal expansion. Especially the compound UPt₃ reveals a large additional contribution below 50 K. The maximum in the α versus T plot roughly coincides with the maximum in the susceptibility (16 K) [1]. The broad nature of this peak gives once more evidence that the anomaly near 16 K cannot be attributed to an antifer-
In a first attempt to describe the data with an electron and phonon contribution, according to

$$\frac{\alpha}{T} = a + bT^2,$$  \hspace{1cm} (1)

the data are presented as $\alpha/T$ versus $T^2$ in fig. 3. For UPt$_3$ such a description is far from appropriate: instead the additional contribution appears as a pronounced upturn. The analysis of the specific heat data of UPt$_3$ was successful with a $T^3\ln T$ contribution, accounting for spin-fluctuation effects and leading to a similar upturn in a plot of $C/T$ versus $T^2$ [2, 4, 5]. Assuming temperature independent Grüneisen parameters the spin-fluctuation contribution to the thermal expansion should follow the same temperature dependence. However, such an analysis leads yet not to satisfying results. This is probably due to a considerable amount of preferred orientation in the polycrystalline sample: preliminary thermal expansion measurements on a single crystalline sample reveal a large anisotropy between the basal plane and the hexagonal axis. Nevertheless we believe that the low-temperature upturn must be ascribed to spin-fluctuation effects.

A similar upturn, although small, can be observed for the compounds UPt$_2$ and UPt$_5$. These anomalies are found in the specific heat as well, and could also be ascribed to spin fluctuations [5]. In orthorhombic UPt$_2$ this contribution might be obscured due to preferred orientations too. For both compounds eq. (1) holds in the temperature interval $50 < T^2 < 250$ K$^2$. Coefficients $a$ and $b$ are listed in table I, together with electron ($\gamma$) and phonon ($\beta$) coefficients from the specific heat analysis. Striking is the large electronic coefficient for UPt$_2$ and the large phonon coefficient for UPt$_5$. 

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Fig. 1. The thermal expansion, $\alpha = 1/d(\Delta L/dT)$, for polycrystalline UPt$_3$, UPt$_2$, and UPt$_5$.

Fig. 2. The relative length changes, $\Delta L/L = (L/L)_{1.4}/(L/L)_{1.4}$, for UPt$_3$, UPt$_2$, and UPt$_5$. 

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Fig. 3. The thermal expansion of UPt₂, UPt₃ and UPt₅ plotted as α/T versus T². The full lines denote fits with coefficients listed in table I. Note the different scales on the vertical axes.

The Grüneisen parameters $\Gamma_e = 3aV_m/(\kappa\gamma)$ and $I_{\text{ph}} = 3bV_m/(\kappa\beta)$ cannot be calculated due to the lack of compressibility data ($\kappa$ will be about $1 \times 10^{-11} \text{m}^2/\text{N}$. However, from the deduced $\kappa\Gamma_e$ values, see table I, it follows that $I_e$ is at least one order of magnitude larger than $I_{\text{ph}}$. A similar observation was made for equiatomic UPt [6]. With the above given estimate for the compressibility of the uranium–platinum compounds, the values for $I_{\text{ph}}$, calculated from the data in table I seem to be too small. Unfortunately, data on corresponding thorium–platinum or lanthanum–platinum compounds are not available. Therefore a more thorough analysis of the various contributions to the thermal expansion is, at this moment, not possible.

Acknowledgement

This work was part of the research program of the Foundation for the Fundamental Research of Matter (FOM), whose financial support is gratefully acknowledged.

References


Table I

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<th>Parameter</th>
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<tr>
<td>α</td>
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<td>γ</td>
<td>mJ/(mol-f.u. $\cdot$ K²)</td>
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<td>$\kappa\Gamma_e$</td>
<td>$10^{-11} \text{m}²/\text{N}$</td>
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<td>β</td>
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<td>$\kappa\Gamma_{\text{ph}}$</td>
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<td>$V_m$</td>
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