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MAGNETIC PROPERTIES OF URuAl AND URhAl SINGLE CRYSTALS

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Abstract. – Single crystals were grown in order to investigate the low temperature magnetic properties of URuAl and URhAl. Both compounds show huge magnetocrystalline anisotropy with the c direction as the easy axis. High field magnetization as well as susceptibility measurements both in the basal plane and along the c axis are presented.

Introduction

URuAl and URhAl crystallize in the hexagonal structure of ZrNiAl type [1]. The lattice parameters as well as the U-U distance are almost equal for the two compounds. URuAl has been found to be paramagnetic down to 20 mK, exhibiting a round maximum in $\chi$ vs. $T$ located at approximately 30 K [2]. A weak upturn was observed above 20 T in the high-field magnetization curves at 4.2 K [3]. URhAl is ferromagnetic below 35 K [4]. Results of an investigation of the pseudo-ternary series U(Ru,Rh)Al were reported earlier [5].

Experimental

To study the anisotropic properties of both URuAl and URhAl we have grown single crystals of both compounds by means of the tri-arc Czochralsky technique. Spheres with diameter of about 3 mm were cut out of the crystals by means of spark erosion. The spheres were subjected to high-field magnetization and susceptibility measurements with the magnetic field applied in the basal plane as well as along the c axis. In figure 1 the results are presented of the susceptibility measurements, obtained in a pendulum magnetometer. It can be seen that the inverse susceptibility measured along the c axis shows some curvature downwards for both compounds. The susceptibility in the basal plane is much lower.

The results of magnetization measurements at 4.2 K performed in the Amsterdam High-Field Installation are shown in figure 2. The measurement along the c axis for URhAl shows a spontaneous magnetization with $\mu_s = 0.94 \mu_B$. No remanence was found in the basal plane. The high-field results also indicate that the upturn in the magnetization curve for URuAl originates entirely from the c axis magnetization, since it is not seen in the basal plane results. The conjecture that

Fig. 1. – Temperature dependence of the inverse susceptibility of the URuAl and URhAl single crystals with the magnetic field in the basal plane and along the c axis. The drawn curves represent the modified Curie-Weiss fit; dotted curves are guides to the eye.

Fig. 2. – Magnetization vs. field for URuAl and URhAl single crystals.
this upturn is a precursor for a metamagnetic transition was not verified in fields up to 38 T.

Discussion

It is clear that for both systems the c axis is the easy axis. The susceptibility curves above about 100 K measured along the c axis, $\chi_\parallel$, can be accurately fitted only by a modified Curie-Weiss law:

$$\chi(T) = C / (T - \theta_p) + \chi_0.$$  

The parameter values resulting from the fits are displayed in Table I, together with the values for the bulk polycrystals, which were obtained on samples displaying some texture. If we consider the features, present in the susceptibility measured with the field in the basal plane, $\chi_\perp$, to be due to an easy axis contribution due to a slight misalignment of the sample with respect to the applied field, we find $\approx 1.5$ degree for URhAl and $\approx 8$ degrees for URuAl to correct for it in such a way that we get a more or less temperature independent susceptibility. That this assumption is correct in the case of URhAl can be inferred from the high-field measurements since the magnetization does not show any spontaneous magnetization in this direction. The same assumption is, however, not correct for URuAl since the misalignment angle is too big. This has led us to perform only a correction procedure on $\chi_\perp$ for URhAl and to consider the $\chi_\perp$ data for URuAl to be correct. A modified Curie-Weiss fit to the corrected data yields results as tabulated in Table I. We also performed a modified Curie-Weiss fit to $1/3\chi_\parallel + 2/3\chi_\perp$, which represents the susceptibility of a polycrystal without preferential orientation, and the resulting values are also represented in Table I. It is worthwhile to note, that the values of $\mu_{\text{eff}}$ found in both directions for URuAl are practically identical. A similar statement cannot be made for URhAl since $\chi_\perp$ can be strongly affected by small misalignment. It can be seen that this weighted sum of $\chi_\parallel$ and $\chi_\perp$ corresponds rather well with the polycrystalline data for URuAl, while for URhAl quite a large discrepancy exists for $\mu_{\text{eff}}$ and $\theta_p$. Here comparison of $\chi_\parallel$ and the susceptibility as measured on a polycrystal reveals that these two quantities are almost equal. This may be due to the strong texture in the polycrystalline samples, and to the relatively high applied magnetic field (3 T), causing a rotation of the sample. This effect did not occur in URuAl presumably since in this compound the susceptibility is much lower. A subsequent measurement on polycrystalline URhAl powder fixed by a small amount of glue coincided perfectly with $1/3\chi_\parallel + 2/3\chi_\perp$ thereby proving the above mentioned explanation.

It is rewarding to note that high-field magnetization measurements performed on an URhAl powder sample free to orient itself in the field can indeed be regarded as representative for a measurement on a single crystal along the easy axis. The free powder data, which are not included in figure 2, show a magnetization value of $\approx 0.8 \mu_B$ when an extrapolation to 0 T is performed, while the corresponding value for the single crystal easy axis is 0.94 $\mu_B$, which is almost exactly twice the value measured on a fixed powder sample: 0.48 $\mu_B$ [5].

Table I. — Comparison between the values resulting from fits to a modified Curie-Weiss law for single crystalline (s.c.) and polycrystalline data. $\chi_\parallel$, $\chi_\perp$: indicates the susceptibility measured with the magnetic field applied parallel and perpendicular to the c axis, respectively. $\chi_\perp$ for URhAl was corrected for an easy axis contribution; see text. Also indicated are the values that result when a modified Curie-Weiss analysis is applied to $1/3\chi_\parallel + 2/3\chi_\perp$. Additionally the Curie temperature for URhAl as obtained by susceptibility measurements is given.

<table>
<thead>
<tr>
<th>crystalline state</th>
<th>$\mu_{\text{eff}}$</th>
<th>$\theta_p$</th>
<th>$\chi_0 / 10^{-9} \text{m}^3 \text{mol}^{-1}$</th>
<th>$T_C$</th>
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<tr>
<td>polycrystal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>s.c. $\chi_\parallel$</td>
<td>2.0</td>
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<td>7</td>
<td>-</td>
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<td>s.c. $\chi_\perp$</td>
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<td>-53</td>
<td>8</td>
<td>-</td>
</tr>
<tr>
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<td>-410</td>
<td>8</td>
<td>-</td>
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<tr>
<td>URhAl</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>s.c. $\chi_\parallel$</td>
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<td>11</td>
<td>-</td>
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<tr>
<td>polycrystal</td>
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<td></td>
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<tr>
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<td>9</td>
<td>27</td>
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<tr>
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<td>32.7</td>
<td>8</td>
<td>28</td>
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<tr>
<td>s.c. $1/3\chi_\parallel + 2/3\chi_\perp$</td>
<td>1.4</td>
<td>32.7</td>
<td>16</td>
<td>28</td>
</tr>
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</table>

Acknowledgements

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