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Title:

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(T=Co, Ir, Pt) COMPOUNDS

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High-field magnetization studies of U_2T_2Sn ($T = Co, Ir, Pt$) compounds

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High-field magnetization measurements at 4.2 K on U_2T_2Sn ($T = Co, Ir$ and Pt) compounds have been performed on free and fixed powders up to 57 T. An antiferromagnetic ground state of U_2Pt_2Sn is corroborated by a metamagnetic transition at 22 T with very small hysteresis going up and down with field. U_2Co_2Sn and U_2Ir_2Sn show no metamagnetic transition up to 57 T which is in agreement with the non-magnetic ground state of these compounds. In all cases, the maximum applied field is not sufficient to achieve saturation. The short-pulse measurements presented here are compared with previous results obtained in quasi-static fields up to 35 T.

Introduction

Recently, a new large isostructural group of U compounds with stoichiometry U_2T_2X ($T =$ late transition metal, $X =$ p-metal) was discovered^{1,2} showing the development of magnetic properties with respect to the constituent elements. This trend on going from the left side and the top to the right and the bottom within the late-transition block of the Periodic Table was observed already in the equiatomic ternary U compounds UTX ³ pointing to the importance of hybridization of f-electronic states with the d- and p- states of the surrounding ligands. In the case of equiatomic UTX compounds, a clear trend from itinerant 5f-electron behaviour (strong delocalization due to hybridization effects) to well developed 5f magnetic

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moments (reduced hybridization) has been found. Similarly, the U_2T_2X compounds containing elements like Fe and Co are non-magnetic Pauli paramagnets due to hybridization of the 5f states with the extended 3d states centred on transition metal. One can find long-range antiferromagnetic order in compounds where T is for instance Pd or Pt^{3,4}. An antiferromagnetic ground state of the ordered samples is corroborated by the metamagnetic transitions in rather high magnetic fields⁴. However, even 38T, the magnetic field available at the University of Amsterdam was not enough to obtain the saturation of magnetization curves. In this paper, we present in addition to our previous studies of other U_2T_2Sn compounds⁵ the high-field magnetizations up to 57 T measured at 4.2 K in the Osaka High Field Facility on three U_2T_2Sn compounds with T = Co, Ir and Pt.

Sample preparation and characterization

U_2T_2Sn compounds with T = Co, Ir and Pt were synthesized by arc-melting appropriate amounts of the constituting elements. The structure and phase purity of the resulting samples were checked by x-ray powder diffraction. Some of the compounds were checked also by means of microprobe analysis. The atomic positions were determined on small single crystals extracted from bulk pieces by means of an Enraf-Nonius four-circle diffractometer². The compound containing Co is found to adopt the ternary derivative version of the tetragonal U_3Si_2 -type of structure (space group $P4/mbm$, $Z = 2$). U_2Ir_2Sn and U_2Pt_2Sn exhibit in contrast to the rest of U_2T_2Sn compounds an additional superstructure with the c-axis parameter doubled with respect to the original U_3Si_2 -type of structure, resulting in space group $P4_2/mnm$ ⁶. The U_3Si_2 -type of structure consists of two alternating plane sheets (Fig. 1), one containing only U atoms at positions 4h ($x, x+0.5, 0.5$) with x about 0.17 and the other containing T atoms (at positions 4g ($y, y+0.5, 0$)) as well as X atoms (at positions 2a ($0, 0, 0$)). In this structure each U atom has seven U neighbours (five within the plane and two along the c axis). Furthermore, each U atom has six transition-metal neighbours and finally, there are four p-metal neighbours for each U atom.

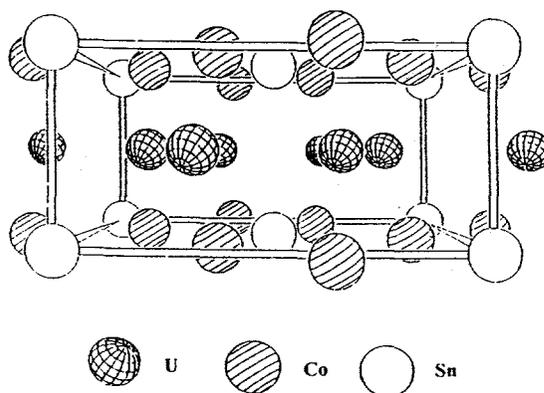


Fig.1.: Schematic representation of the structure of U_2Co_2Sn .

Depending on the choice of T and X, the distance of U neighbours along the c-axis can be smaller or larger than the distance of the U neighbours within the plane.

The structure of U_2Pt_2Sn and U_2Ir_2Sn can be described as a derivative of the U_3Si_2 -type of structure where relatively large Pt and Ir atoms force U atoms to move in the perpendicular direction to the transition metal links. The U atoms thus occupy two inequivalent crystallographic positions (4f and 4g) within the space group $P4_2/mnm$ forming zig-zag chains along the c-axis.

Experimental results and discussion

The majority of the U_2T_2Sn samples exhibits antiferromagnetic ordering with transition temperatures ranging from 14.3 K for U_2Ni_2In to 40.6 K for U_2Pd_2Sn ⁴. U_2Pt_2Sn is situated at the low-temperature border of the ordered systems: it orders antiferromagnetically at 15.4 K. The compounds U_2Co_2Sn and U_2Ir_2Sn are paramagnetic down to 1.3 K. An antiferromagnetic ground state of the ordered samples is corroborated by the metamagnetic transitions at 4.2 K⁴. Nevertheless, the previous high-field magnetization studies at the University of Amsterdam in quasi-static fields up to 35 T have shown that even these fields are not sufficient to saturate the magnetization in most of the cases and in the case of antiferromagnetic ordered systems sometimes not even high enough to cause a metamagnetic transition⁴. Therefore, we have extended our studies to short-pulse fields up to 57 T at the High Field Facility at Osaka University.

In Fig. 2 measurements performed on two kinds of samples of U_2Co_2Sn are depicted which is reported to be paramagnetic down to 1.3 K^{4,7}. The first type of sample is a fine powder consisting of (presumably) single-crystalline particles which are free to be oriented by the external magnetic field. A measurement on this type of sample represents a measurement along the easy magnetization direction. In the second type of sample, the powder is fixed by frozen alcohol in a random orientation and

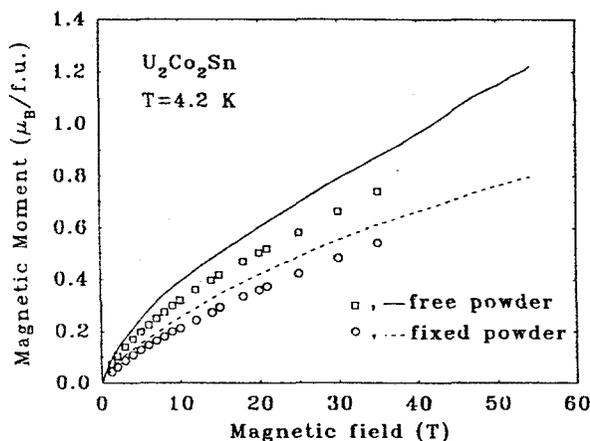


Fig.2.: Field dependence of the magnetization in quasi-static fields of U_2Co_2Sn for powder free to orient in the external field (□) and for powder fixed by frozen alcohol (○). The lines represent continuous-field sweeps.

the measurement represents an experiment on an ideal polycrystalline sample. No metamagnetic transition on the slightly bended magnetization curves is detected at 4.2 K. The magnetization values measured up to 57 T in pulse magnetic field are considerably higher with respect to the values obtained in the quasi-static fields where the applied magnetic field is kept constant for 0.1 s to avoid influence of the eddy currents. We may attribute this problem to the different scaling factors of the two high-field installations. Nevertheless, the results from both experiments are qualitatively the same. When we re-scale the results performed in fields up to 55 T to the quasi-static fields we get for the free-powder magnetization a value of $1.03 \mu_B/\text{f.u.}$ at 55 T. For the fixed powder a somewhat smaller value of $0.71 \mu_B/\text{f.u.}$ is obtained at the same field value. For both types of $\text{U}_2\text{Co}_2\text{Sn}$ samples no clear tendency to saturation at high fields is observed.

The fact that the magnetization curves for the paramagnetic material are different, for the free powder reaching higher values, points to the presence of the field-induced moments. The resulting magnetic response is anisotropic due to hybridization between the 5f-states of the U atoms on one side and the 5f-states with the d-states of the Co atoms on the other, which is highly anisotropic.

Although only in the case of magnetic saturation a firm conclusion can be drawn regarding the type of magnetic anisotropy by comparing the saturated values of magnetization for fixed M_{fix} and free powder M_{free} of the magnetically ordered system, there is no need for saturation for paramagnetic materials. From the observed ratio $M_{\text{fix}}/M_{\text{free}}$ which amounts 0.69 at 55 T we may conclude that $\text{U}_2\text{Co}_2\text{Sn}$ does not exhibit uniaxial type of magnetic anisotropy.

The magnetization measurements on $\text{U}_2\text{Pt}_2\text{Sn}$ which orders antiferromagnetically below 15.4 K^{4,7} are shown in Fig. 3. A broad metamagnetic transition at 22 T is observed in the experiments with free and fixed powders. The magnetization curves measured with increasing and decreasing field are nearly identical showing only very small hysteresis

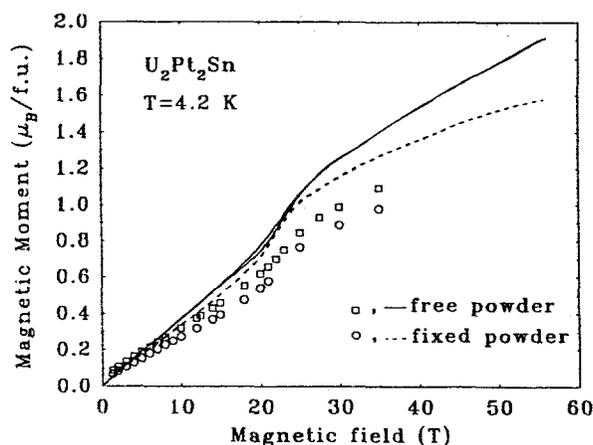


Fig.3.: Field dependence of the magnetization in quasi-static fields of $\text{U}_2\text{Pt}_2\text{Sn}$ for powder free to orient in the external field (\square) and for powder fixed by frozen alcohol (\circ). The lines represent continuous-field sweeps.

around the metamagnetic transition in the case of free powder. Similar to the case of U_2Co_2Sn , the data values at the High Field Facility at Osaka University are considerably higher with respect to the previous measurements in the quasi-static fields up to 35 T preserving the same shape of the magnetization curves and the value of the field where the metamagnetic transition takes place. After renormalization to the values obtained in the quasi-continuous fields, the magnetization which does not exhibit any saturation tendency yields a value of $1.23 \mu_B/f.u.$ at 56 T for the free-powder sample. The magnetization curve obtained for the fixed-powder sample also exhibits a metamagnetic transition at 22 T and has a magnetization of $1.23 \mu_B/f.u.$ at 56 T. Also in this case, the magnetization curve is far from saturation. The observed ratio M_{fix}/M_{free} which amounts to 0.82 suggests that also U_2Pt_2Sn does not exhibit uniaxial type of magnetic anisotropy. In the present case, one has to be extremely careful because one is dealing with magnetically ordered system and one cannot exclude another metamagnetic transition even at higher field to occur changing the ratio M_{fix}/M_{free} .

The magnetization curves for U_2Ir_2Sn , which is reported to be paramagnetic down to 1.3 K^{4,7}, are depicted in Fig.4. For both types of samples no metamagnetic transitions are found, in agreement with paramagnetic ground state. The data taken in both high-field laboratories are in this case quantitatively different. While no difference between the free and fixed powder sample results taken at the High Field Facility at Osaka University in short pulse fields can be traced out, the results in quasi-static fields up to 35 T are qualitatively similar to the case of U_2Co_2Sn . The possible explanation is that the grains of the so-called free powder are not free enough to be oriented by the external field along the direction with the maximal magnetic response due to the very short pulse duration.

However, it is clear that the magnetizations do not saturate even at 57 T. From the ratio M_{fix}/M_{free} at the 35 T which amounts to 0.71, we conclude that U_2Ir_2Sn does not exhibit uniaxial type of magnetic anisotropy.

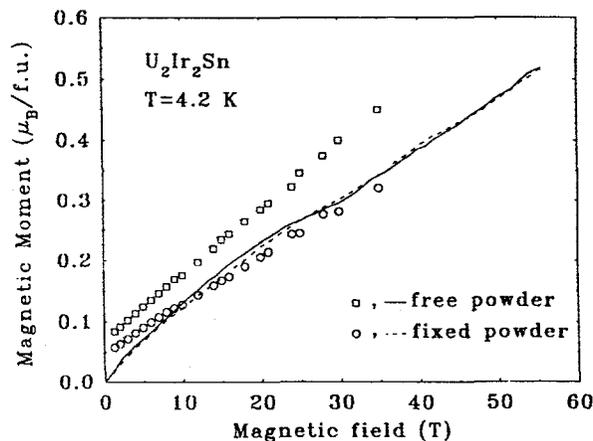


Fig.4.: Field dependence of the magnetization in quasi-static fields of U_2Ir_2Sn for powder free to orient in the external field (\square) and for powder fixed by frozen alcohol (\circ). The lines represent continuous-field sweeps.

Conclusion

We have reported the high-field magnetizations of three U_2T_2Sn ($T = Co, Ir$ and Pt) compounds measured at 4.2 K in two different high-field installations. The results taken at the High Field Facility at Osaka University in short-pulse fields are qualitatively similar with the ones obtained previously in quasi-static fields up to 35 T at the University of Amsterdam. The differences can be attributed to different scaling factors of both installations and/or to imperfect alignment of the grains during very short field pulses. To determine the magnetocrystalline anisotropy, two types of samples were used. Fine powder which is free to be aligned by the external applied field and the powder fixed by frozen alcohol.

The magnetization curves of U_2Pt_2Sn show a metamagnetic transition at about 22 T with small hysteresis going up and down with the field. This finding is in agreement with the antiferromagnetic ground state of this compound at low temperatures. U_2Co_2Sn and U_2Ir_2Sn show no metamagnetic transition up to 57 T which is in agreement with the paramagnetic state at 4.2 K.

In all cases, we did not observe any tendency of the magnetization towards saturation. A possible explanation are field-induced magnetic moments. Due to anisotropic hybridization of the 5f states of the U atoms with the d-states of the transition metal ligands, the resulting magnetizations measured on free and fixed powder are different.

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