UvA-DARE (Digital Academic Repository)

Pressure effect on spin reorientation transition in U3As4

Bakker, K.; Wisniewski, P.; Henkie, Z.; Franse, J.J.M.; Olesky, CZ.

DOI

[10.1016/0304-8853\(94\)00609-1](https://doi.org/10.1016/0304-8853(94)00609-1)

Publication date

1995

Published in

Journal of Magnetism and Magnetic Materials

[Link to publication](#)

Citation for published version (APA):

Bakker, K., Wisniewski, P., Henkie, Z., Franse, J. J. M., & Olesky, CZ. (1995). Pressure effect on spin reorientation transition in U3As4. *Journal of Magnetism and Magnetic Materials*, 140-144, 1427-1428. [https://doi.org/10.1016/0304-8853\(94\)00609-1](https://doi.org/10.1016/0304-8853(94)00609-1)

General rights

It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

Disclaimer/Complaints regulations

If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: <https://uba.uva.nl/en/contact>, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.

Pressure effect on spin reorientation transition in U_3As_4

K. Bakker^a, P. Wiśniewski^b, Z. Henkie^{b,*}, J.J.M. Franse^a, Cz. Oleksy^c

^a University of Amsterdam, Van der Waals–Zeeman Laboratory, Valckenierstraat 65–67, 1018 XE Amsterdam, The Netherlands

^b Trzebiatowski Institute for Low Temperature and Structure Research, P.O. Box 937, 50-950 Wrocław, Poland

^c Institute of Theoretical Physics, Wrocław University, pl. Maxa Borna, 9, 50-204 Wrocław, Poland

Abstract

A linear increase in the critical field H_c (> 200 kOe) with pressure p (0–0.5 GPa) was observed for the spin reorientation transition in U_3As_4 by measurements of magnetisation along the $\langle 100 \rangle$ axis at 5 K; $dH_c/dp = 76$ kOe/GPa. An interpretation of the results and a magnetic phase diagram for the U_3X_4 pnictides are proposed.

U_3X_4 pnictides are ferromagnetically ordered and yet hybridised systems. The hybridisation-mediated two-ion interaction leads to a highly anisotropic noncollinear ferromagnetic phase proved for U_3P_4 ($T_C = 138$ K) and U_3As_4 ($T_C = 196$ K) by neutron diffraction [1]. Discovery of the field-induced phase transition in U_3As_4 at $H_c = 190$ kOe and $T = 4.2$ K [2] was fruitful in the examination and understanding of magnetism of this compound [3,4]. We present here the effect of pressure on its H_c .

The U_3As_4 cylindrical sample with diameter 1.6 mm and length 6 mm along the $\langle 100 \rangle$ axis was prepared from a single crystal grown by the chemical vapour transport method. The magnetisation in a magnetic field up to 300 kOe parallel to the axis of the sample was measured both outside and inside a pressure vessel. The measurements were made at temperature 5 K and under pressure varying from 0 to 0.5 GPa. Other details of the experiment are the same as described in Ref. [5].

Fig. 1 shows that the dependence of magnetisation σ on the magnetic field is different for two different U_3As_4 crystals. This has not been noticed before. The specific feature of sample 1 is that the magnetisation along the $\langle 100 \rangle$ axis at $H > H_c$ is identical to the spontaneous magnetisation along the $\langle 111 \rangle$ axis. For sample 2 the magnetisation above H_c is clearly enhanced. In order to understand this effect we have compared this behaviour with that predicted by the spin Hamiltonian model of Przystawa [4].

The Przystawa model is closely related to the crystal structure of the U_3X_4 pnictides (bcc of Th_3P_4 -type), which possess three different types of U sites, all with uniaxial crystal potential. The local symmetry axes fall along three

different cubic axes for the three different types of U sites, and D is the crystal field parameter. The two-ion anisotropic exchange-interaction tensor is characterised by components J and K . The hitherto most advanced application of this model to the study of the U_3X_4 pnictides was for the spin $S = 1$ in Ref. [4], where the model is also described.

The present calculations have been done for the spin $S = 5/2$, which is more closely related to the paramagnetic moment of U_3As_4 , $\mu_{\text{eff}} = 2.94\mu_B$. We have obtained better quantitative agreement between the calculated $\sigma(T)$ dependence and experimental results. The zero-field phase diagram for this case is shown in inset a in Fig. 1. It predicts two areas of parameters giving noncollinear ferromagnetic (NCFo) phases. Each phase has three sublattices and resulting magnetic moments along the $\langle 111 \rangle$ axis. Magnetic moments of particular U^{4+} ions are tilted by the exchange interactions from the cubic axes toward the body diagonal direction in the case of NCFo-1 structure, or pass on the other side of the diagonal (between the $\langle 111 \rangle$ and $\langle 110 \rangle$ axes) in the case of the NCFo-2 structure. The NCFo-1 structure has been found for U_3P_4 and U_3As_4 by neutron experiments [1]. The NCFo-1 and NCFo-2 areas are separated by the area of collinear ferrimagnetic (CFi) structure. In this case the magnetic moments flop from two cubic edges onto the third one. The flopped moments are slightly reduced with respect to the remaining one, but all moments are parallel to each other and to the $\langle 100 \rangle$ axis. The temperature and magnetic field dependent magnetisation for U_3Sb_4 ($T_C = 140$ K) is consistent with that expected for the CFi phase [4].

The theoretical magnetisations for phases NCFo-1 and NCFo-2, plotted in Fig. 1, are multiplied by the factors 0.802 and 0.883, in order to obtain the same spontaneous magnetisations for the $\langle 100 \rangle$ axis as the experimental ones for the samples 1 and 2, respectively. This correction is

* Corresponding author. Fax: +48 (71) 441029.

applied to show the correspondence between sample 1 and phase NCFo-1, or sample 2 and phase NCFo-2. It is not clear to us why both structures can exist alternately for the same composition.

$H_c = 191$ kOe is the lowest reported for the examined phase transition in U_3As_4 at 4.2 K [3]. Our zero-pressure determination of H_c for sample 2 outside and inside the pressure vessel gives values of 205 and 230 kOe, respectively. In terms of the Przystawa model this discrepancy is due to misalignment between the $\langle 100 \rangle$ axis and the magnetic field. This effect, shown in inset b in Fig. 1, is consistent with the resulting inaccuracy of sample positioning in the pressure vessel ($< 2^\circ$) and then in magnetic field ($< 2^\circ$). We have also found that the misalignment cannot be responsible for the discovered magnetic moment enhancement above H_c .

The Przystawa model allows us to describe the magnetisation for U_3Sb_4 , U_3As_4 and U_3P_4 one after the other when increments of $D/2J$ and simultaneous decrements of K/J are proportional to the corresponding decrements of $O = U-U$ distance in these compounds. Hence O scales H_c in the model. Furthermore, it was found that (dT_C/dp) (dp/dO) determined for a particular compound follows the slope of T_C versus O dependence for compounds of this series [6,7]. Thus we propose the magnetic phase diagram shown in Fig. 2, following the linear pressure dependence of the H_c shown in the inset of Fig. 2 and using compressibility data from Ref. [6].

Fig. 1. Magnetisation along the $\langle 100 \rangle$ axis for samples 1 (open circles) and 2 (full circles). The magnetisation calculated in terms of the Przystawa model corresponding to parameters of non-collinear phases NCFo-1 and NCFo-2 (shown in the phase diagram of inset a by open and full circles respectively) are given by solid and broken lines, respectively. Inset b shows the dependence of H_c for the NCFo-1 phase on the misalignment angle between the $\langle 100 \rangle$ axis and the field direction when the latter is tilted towards either the $\langle 111 \rangle$ or the $\langle 011 \rangle$ axis.

Fig. 2. Qualitative phase diagram for the U_3X_4 pnictides at ~ 4.2 K. Dotted line, boundary between the NCFo-1 and CFI phases in a magnetic field along the $\langle 100 \rangle$ axis; dashed line, the same boundary in a magnetic field along the $\langle 111 \rangle$ axis. Data taken from other papers are given by: $\times$ [1]; $\circ$ [3]; $\blacksquare$ [4]. Inset: pressure dependence of H_c for sample 2.

It can be concluded that for $H \parallel \langle 100 \rangle$ the diagram predicts H_c equal to 790 and 0 kOe for $U-U$ distances corresponding to the compounds U_3P_4 and U_3Sb_4 , respectively. In the case of $H \parallel \langle 111 \rangle$ a small negative value of dH_c/dp is expected for U_3Sb_4 . Experimental data show that no field-induced phase transition was found in fields up to 500 kOe for U_3P_4 [8]. We also know that at $H = 0$ the NCFo-1 magnetic structure is observed for U_3As_4 , while the magnetisation for U_3Sb_4 strongly suggests that it already has the CFI structure.

Acknowledgements: We thank Professor J. Przystawa for stimulating discussions. This work was supported in part by the Polish Committee for Scientific Research, grant no. KBN-2 P302 173 06.

References

- [1] P. Burlet, J. Rossat-Mignot, R. Troć and Z. Henkie, Solid State Commun. 39 (1981) 745.
- [2] P. Novotny and J. Sternberg, Phys. Stat. Sol. (a) 33 (1976) K15.
- [3] K. Bakker, P. Wiśniewski, Z. Henkie and J.J.M. Franse, Acta Phys. Polon. 85 (1994) 245.
- [4] R. Maślanka, Z. Henkie, J.J.M. Franse, R. Verhoef, Cz. Oleksy and J. Przystawa, Physica B 159 (1989) 181.
- [5] K. Bakker, A. de Visser, L.T. Tai, A.A. Menowsky and J.J.M. Franse, Solid State Commun. 86 (1993) 497.
- [6] Z. Henkie, P. Wiśniewski, R. Fabrowski and R. Maślanka, Solid State Commun. 79 (1991) 1025.
- [7] Z. Henkie, R. Maślanka and K. Durczewski, Physica 144 B (1986) 92.
- [8] T. Suzuki, S. Takagi, N. Niitsuma, K. Takegahara, T. Kasuya, A. Yanase, T. Sakakibara, M. Date, P.J. Markowski and Z. Henkie, in: High Field Magnetism, ed. M. Date (North-Holland, Amsterdam, 1983) p. 183.