Effect of pressure on first-order valence transition of $Yb_{1-x}Y_xInCu_4$

Wei Zhang [a,*], Kazuyoshi Yoshimura [a], Akihiro Mitsuda [b,1], Tsuneaki Goto [b]

[a] *Department of Chemistry, Graduate School of Science. kyoto University, Kyoto 606-8502, Japan*

[b] *The Institute for Solid State Physics, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa-shi, Chiba 277-8581, Japan*

Abstract

$YbInCu_4$ exhibits a first-order valence transition at $T_v \approx 42$ K with 0.5% increase of volume. The inherent chemical pressure in $Yb_{1-x}Y_xInCu_4$ system is discussed as negative on valence transition of $YbInCu_4$. The external pressure effect on H_v of $Yb_{1-x}Y_xInCu_4$ is measured as $\frac{dH_v}{dP} \approx$ -1 T $kbar^{-1}$.

Key words: magnetization measurement; valence transition; pressure effect; $YbInCu_4$
PACS: 71.20.Eh, 71.28.+d, 75.20.Hr, 75.30.Mb

1. Introduction

$YbInCu_4$ exhibits a first-order valence transition from the Yb^{3+} state to an intermediate valence (IV) state at transition temperature $T_v \approx 42$ K with abrupt changes in lattice volume, meanwhile the IV state can be changed to the Yb^{3+} state at transition magnetic field $H_v \approx 33$ T [1–3]. Pressure effect on T_v of $YbInCu_4$, $\frac{dT_v}{dP} \approx$ -2 K $kbar^{-1}$, is consistent with favoring the smaller Yb^{3+} state [4,5]. The negative inherent chemical pressure (P_{in}) obtained by substituting Yb with a larger ion increases T_v significantly [2,4]. However, $Yb_{1-x}Y_xInCu_4$ is an exceptional system: though the P_{in} produced by Y-substitution is negative, T_v and H_v decrease as x increases [6–8]. In this work the effect of external pressure (P_{ex}) on valence transition of $Yb_{1-x}Y_xInCu_4$ was investigated by measurement of magnetization under various fixed high pressures using an induction method. According to the x-ray-diffraction analysis, the single-crystalline samples grown from the $InCu_2$-flux are single phase with $AuBe_5$-type structure. The lattice parameters (a) were calculated using (422), (333), and (440) reflections.

* Corresponding author. Fax: +81-75-753-4000
Email address: wzhang@kuchem.kyoto-u.ac.jp (Wei Zhang).
1 Present address: Department of Physics, Toyama University, 3190 Gofuku, Toyama 930-8555, Japan

2. Results and Discussion

For $Yb_{1-x}Y_xInCu_4$, the concentration dependence of a is shown in Fig. 1. $YbInCu_4$ has the compressibility of $\kappa =$ 0.99 $Mbar^{-1}$ [5], if the value of $\frac{da}{dx}$ is 0.03 for x< 0.3, the effect of Y-substitution is $\frac{dP_{in}}{dx} =$ -12 kbar. The P_{in} effect on T_v can be estimated as $(\frac{dT_v}{dx})_{in} = 24$ K. The concentration dependence of calculated T_v for $Yb_{1-x}Y_xInCu_4$ has been plotted in Fig. 1.

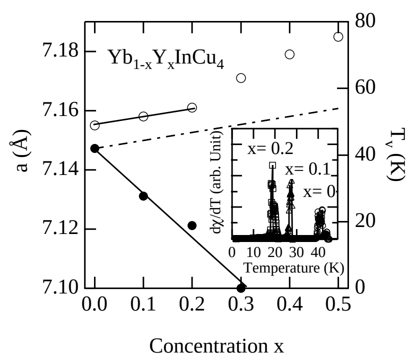

Fig. 1. Concentration dependences of a (○), T_v (●) determined from magnetic susceptibility derivative $\frac{d\chi}{dT}$ measurements and T_v (dashed line) calculated from P_{in} for $Yb_{1-x}Y_xInCu_4$. The inset is the temperature dependences of $\frac{d\chi}{dT}$. The straight solid lines are to guide the eye.

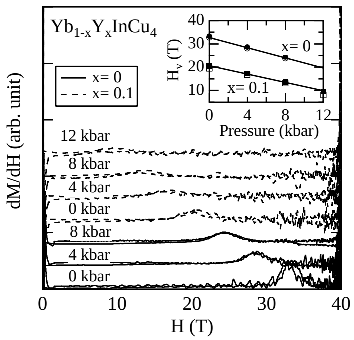

Fig. 2. The magnetization derivatives of $\frac{dM}{dH}$ *vs* H for x= 0, 0.1 under various P_{ex} at 4.2 K. The inset shows pressure dependences of H_v determined from $\frac{dM}{dH}$ under various fixed P_{ex}. The solid symbols are H_v determined by increasing-field sweeps, the empty symbols are H_v determined by decreasing-field sweeps (see text for details). The lines are to guide the eye

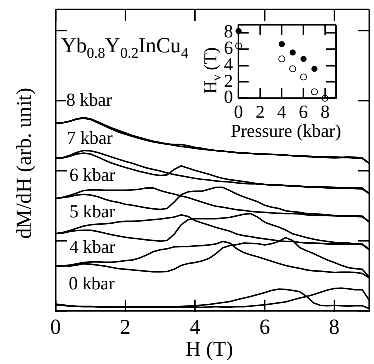

Fig. 3. The magnetization derivatives of $\frac{dM}{dH}$ *vs* H for x= 0.2 under various P_{ex} at 0.6 K. The inset shows pressure dependence of H_v determined from $\frac{dM}{dH}$ under various fixed P_{ex}. H_v^{up} (●) is determined by increasing fields sweep, H_v^{down} (○) is determined by decreasing field sweep (see text for details).

The temperature dependence of magnetic susceptibility derivative $\frac{d\chi}{dT}$ is displayed in the inset of the Fig. 1. The concentration dependence of T_v determined from the maxima of $\frac{d\chi}{dT}$ is also plotted in the Fig. 1. T_v shifts to the low-temperatures (LT) as $(\frac{dT_v}{dx})_{exp}$= -140 K. The critical concentration x_c is around 0.3. At $x\leq 0.3$, besides P_{in} effect, the substitution effect $(\frac{dT_v}{dx})_{sub}$ should contribute to suppress T_v. According to $(\frac{dT_v}{dx})_{exp}=(\frac{dT_v}{dx})_{sub}+(\frac{dT_v}{dx})_{in}$, Y-substitution effect is estimated as $(\frac{dT_v}{dx})_{sub}$= -164 K, which can be explained by the destabilization of the Kondo coherent state at LT [7,8].

High magnetic field (H) is able to change the IV state into the Yb^{3+} state at H_v and the hysteresis is observed in the high-field magnetization curves in consequence of a first-order character of the transition [3]. The transition occurs at higher H in increasing-field sweeps as compared to decreasing-field sweeps. We show the magnetization derivatives $\frac{dM}{dH}$ *vs* H under various P_{ex} for x= 0, 0.1 measured at 4.2 K and for x= 0.2 measured at 0.6 K in Figs. 2 and 3, respectively. The fact that H_v estimated from the maxima of $\frac{dM}{dH}$ decreases with pressure [as shown in the insets of Figs. 2 and 3] is in agreement with $\frac{dT_v}{dP}\approx$ -2 K $kbar^{-1}$. Linear fits give the values $\frac{dH_v}{dP}$= -1.1 T $kbar^{-1}$ for x= 0, $\frac{dH_v}{dP}$= -1.0 T $kbar^{-1}$ for x= 0.1, $\frac{dH_v}{dP}$= -1.4 T $kbar^{-1}$ for x= 0.2. The larger volume of $Yb_{0.8}Y_{0.2}InCu_4$ makes it more sensitive to P_{ex} and cause the increase of $|\frac{dH_v}{dP}|$.

In conclusion, the P_{in} is negative because the volume of $YbInCu_4$ expands with Y-substitution, meanwhile T_v and H_v shift to lower temperatures and lower fields, resulting in the suppression of the transition at x_c= 0.3 of $Yb_{1-x}Y_xInCu_4$. The effect of P_{ex} on the first-order valence transition of $Yb_{1-x}Y_xInCu_4$ ($x < x_c$) has been studied by measurement of high-field magnetization curves under various fixed pressures at LT. The H_v decrease with pressure for all the samples with $x < x_c$ as $\frac{dH_v}{dP}\approx$ -1 T $kbar^{-1}$.

Acknowledgements

We are very grateful to Prof. K. Kosuge and Dr. M. Kato for valuable discussions. This work was performed under the auspices of the Ministry of Education, Science and Culture of Japan and supported from JSPS through Grant No. 12440195.

References

[1] I. Felner, I. Nowik, Phys. Rev. B **33** (1986) 617.

[2] I. Felner, I. Nowik, D. Vaknin, U. Potzel, J. Moser, G. M. Kalvius, G. Wortmann, G. Schmiester, G. Hilscher, E. Gratz, C. Schmiester, N. Pillmayr, K. G. Prasad, H. de Waard, H. Pinto, Phys. Rev. B **35** (1987) 6956.

[3] K. Yoshimura, T. Nitta, M. Mekata, T. Shimizu, T. Sakakibara, T. Goto, G. Kido, Phys. Rev. Lett. **60** (1988) 851.

[4] I. Nowik, I. Felner, J. Voiron, J. Beille, A. Najib, E. du Tremolet de Lacheisserie, G. Gratz, Phys. Rev. B **37** (1988) 5633.

[5] J. M. De Teresa, Z. Arnold, A. del Moral, M. R. Ibarra, J. Kamarád, D. T. Adroja, B. Rainford, Solid State Commun. **99** (1996) 911.

[6] H. Nakamura, M. Shiga, Physica B **206 & 207** (1995) 364.

[7] K. Yoshimura, N. Tsujii, K. Sorada, T. Kawabata, H. Mitamura, T. Goto, K. Kosuge, Physica B **281 & 282** (2000) 141.

[8] W. Zhang, N. Sato, K. Yoshimura, A. Mitsuda, K. Sorada, H. Mitamura, T. Goto, K. Kosuge, J. Phys. Chem. Solids **63** (2002) 1215.