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# Magnetic and structural properties of $\text{Lu}_2(\text{Fe}, \text{Mn})_{17}\text{H}_y$ hydrides

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## Abstract

The  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x\text{H}_y$ ,  $x = 0-2$ ,  $y = 0-3$ , hydrides with the  $\text{Th}_2\text{Ni}_{17}$ -type crystal structure were prepared and their structural and magnetic parameters were studied. The lattice parameters measured at room temperature increase smoothly with H content. The magnetic measurements indicate that the  $\text{Lu}_2\text{Fe}_{17}\text{H}_y$  hydrides (with  $y$  up to 1.77) are antiferromagnets at high temperatures and ferromagnets at low temperatures. The  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}$  compound also has a high temperature antiferromagnetic state, but its hydrides are ferromagnets only. The  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x\text{H}_y$  hydrides, with  $x = 0.7$  and 2, are ferromagnets with  $T_c$  monotonically increasing with H content. The saturation magnetization measured for  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x\text{H}_y$ , ( $x = 0, 0.5, 0.7, 2$  and  $0 < y < 3$ ) hydrides is practically insensitive to hydrogen concentration changes.

(Some figures in this article are in colour only in the electronic version)

## 1. Introduction

The structural and magnetic properties of the  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x$  ( $x = 0-2$ ) system have been extensively studied recently [1]. These compounds crystallize with a hexagonal  $\text{Th}_2\text{Ni}_{17}$ -type crystal structure. The  $\text{Lu}_2\text{Fe}_{17}$  binary compound is a collinear ferromagnet below  $\Theta_T = 135$  K and a helical antiferromagnet in the temperature range from  $\Theta_T$  up to the Néel temperature  $T_N = 278$  K [1, 2]. The compounds  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x$  with  $x = 0-0.5$  are ferromagnets at low temperatures and antiferromagnets at high temperatures. They are only ferromagnets with an almost constant value of the Curie temperature,  $T_C(x)$ , when  $x \geq 0.7-2$ . The temperature  $\Theta_T$  of the ‘ferromagnet–antiferromagnet’ phase transition for  $x = 0-0.5$  rises fast from 135 to 253 K with Mn content, whereas the Néel temperature is practically unchanged ( $\sim 278$  K) and close to  $T_C(0.7) = 287$  K. The saturation magnetization of the  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x$  compounds decreases with the increase in Mn concentration. This is explained by the antiparallel coupling of both Fe and Mn magnetic moments against each other [1].

The increase of  $T_C$  with Mn content increase in the  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x$  ( $x = 0-1$ ) system is unexpected because

in the other  $\text{R}_2\text{Fe}_{17-x}\text{Mn}_x$  compounds the ferromagnetic temperature,  $T_C$ , decreases or is almost constant, at least for  $x = 0-1$  (see [1]). The lattice constants  $a$  and  $c$  in the  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x$  systems continue to rise with Mn concentration [1]. It was found that hydrogenation of the  $\text{Lu}_2\text{Fe}_{17-x}\text{Si}_x\text{H}_y$  [3],  $\text{Ce}_2\text{Fe}_{17}\text{H}_y$  [4] and  $\text{Ce}_2\text{Fe}_{17-x}\text{Mn}_x\text{H}_y$  [5–7] systems, when the  $y$  index is in the range of  $y \leq 2$ , causes the  $T_C$  to increase, leaving the lattice parameter  $c$  unchanged, or even slightly diminished. This is somewhat unusual because the  $\text{R}_2\text{Fe}_{17}$  compounds were observed to have a linear relationship between the  $T_C$  and lattice parameters, as a rule. Keeping this in mind, we decided to perform magnetic and crystallographic investigations to establish the relationship between the lattice parameters and the Curie temperature in the hydrogenated  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x$  alloys. We have taken this opportunity to also draw attention to the situations of the ferromagnetic state in the  $\text{Lu}_2\text{Fe}_{17}\text{H}_y$  hydride with  $y = 0.8$  [3] and the antiferromagnetic ordering for the hydride  $y = 3$  [8]. It is important to understand this because ferromagnetism of  $\text{R}_2\text{Fe}_{17}\text{H}_y$  usually gets stronger when hydrogen content in these alloys increases [4]. In this report, the structural and magnetic properties of  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x\text{H}_y$ ,  $x = 0-2$ ,  $0 < y < 3$ , hydrides are investigated for the first time.

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**Table 1.** Structural and magnetic properties of  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x\text{H}_y$  hydrides.

$x$	$y$	$a$ (Å)	$c$ (Å)	$V$ (Å <sup>3</sup> )	$\Theta_T$ (K) <sup>a</sup>	$T_N$ (K) <sup>a</sup>	$T_C$ (K)	$M_{\text{sat}}$ ( $\mu_B/\text{f.u.}$ ) <sup>b</sup>
0	0	8.374	8.266	501.986	153	276	—	33.9
	0.5	8.405	8.271	506.016	177	279	—	33.5
	0.73	8.402	8.279	506.144	196	280	—	34.7
	0.96	8.429	8.344	513.401	206	280	—	34.4
	1.77	8.468	8.296	515.183	236	287	—	34.8
0.5	0	8.379	8.264	502.464	249	276	—	31.8
	0.15	8.382	8.267	503.007	—	—	271	36.3
	0.39	8.385	8.299	505.315	—	—	284	33.8
	0.71	8.412	8.285	507.717	—	—	285	31.8
0.7	0	8.387	8.265	503.485	—	—	287	30.6
	0.74	8.425	8.294	509.841	—	—	295	31.6
	2.72	8.463	8.295	514.512	—	—	428	30.3
2.0	0	8.387	8.271	503.851	—	—	292	26.8
	0.56	8.4	8.269	505.292	—	—	303	27.9
	1.09	8.419	8.289	508.808	—	—	332	26.2
	1.86	8.438	8.298	511.662	—	—	359	27.6

<sup>a</sup>  $\Theta_T$  and  $T_N$  for  $\text{Lu}_2\text{Fe}_{17}\text{H}_y$  have been measured during sample heating [9].

<sup>b</sup>  $M_{\text{sat}}$  at 1.8 K.

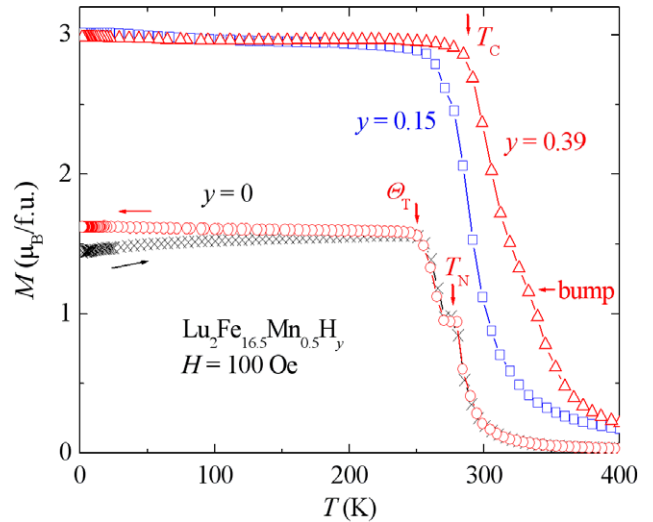
## 2. Experimental details

The studied  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x$  compounds ( $x = 0, 0.2, 0.5, 0.7, 2$ ) were prepared by arc melting from starting materials. The ingots were homogenized at 1450 K for 9 h and then quenched in water. The x-ray diffraction measurements were carried out with a DRON diffractometer using Fe  $K\alpha$  radiation. The  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x\text{H}_y$  hydride samples, with  $y = 0-3$ , were prepared in a volumetric apparatus through the direct absorption of hydrogen by metallic samples at 423 K. The hydrogen content  $y$  in the samples was determined with an accuracy of  $\pm 0.02$  by measurements of the hydrogen pressure drop in a calibrated apparatus volume. According to x-ray analysis, all the  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x$  compounds ( $x = 0-2$ ) and their hydrides have a hexagonal crystal structure, which to a first approximation can be attributed to the  $\text{Th}_2\text{Ni}_{17}$  type. The lattice parameters were calculated using the DICVOL program.

Magnetization measurements were performed with a SQUID magnetometer. The magnetization curves  $M(H)$  were measured on free powder in a field up to 55 kOe at  $T = 1.8$  K. The saturation magnetization  $M_{\text{sat}}$  was determined by extrapolation of experimental dependences  $M(1/H)$  to  $1/H \rightarrow 0$ . Temperature dependences of magnetization  $M(T)$  in a field of 100 Oe and in the temperature range of (2–400) K were studied on fixed powders or polycrystalline samples. The temperatures of the magnetic phase transitions  $T_N$ ,  $T_C$  and  $\Theta_T$  were determined from the  $M(T)$  dependences.

## 3. Experimental results

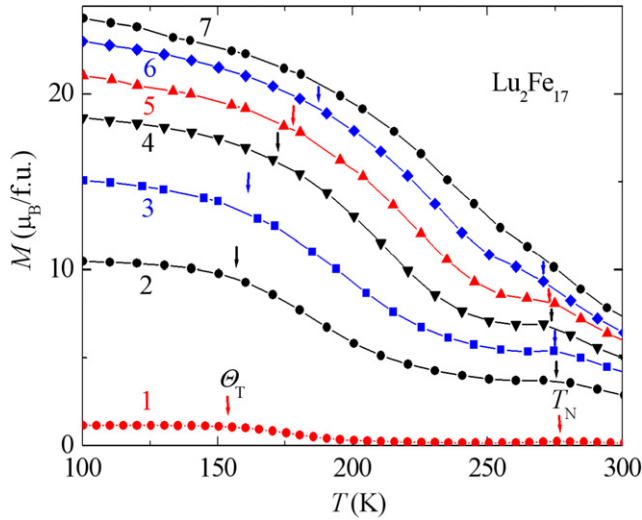
The structural data for the initial non-hydrogenated  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x$  ( $x = 0-0.7$ ) alloys have already been published [1, 9]. In table 1, the lattice parameters for the hydrogenated samples of  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x\text{H}_y$  ( $x = 0-0.7, y = 0-3$ ) at room temperature are presented. As one can see, the crystal lattice unit is enhanced in the basal plane and elongated along



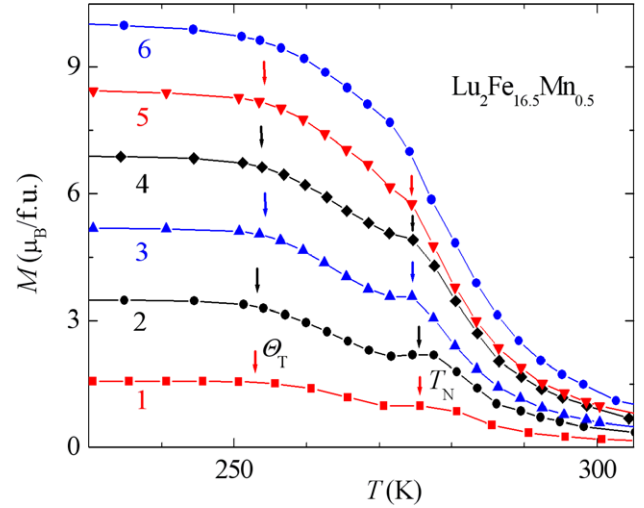
**Figure 1.** Temperature dependences of the magnetization of the  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}$  ( $x, \text{O}$ ),  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}\text{H}_{0.15}$  ( $\square$ ) and  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}\text{H}_{0.39}$  ( $\triangle$ ) alloys measured in a field of 100 Oe. The vertical arrows indicate the  $\Theta_T$ ,  $T_C$  and  $T_N$  values.

the  $c$  axis after hydrogenation. These results are different when compared with those reported for  $\text{Lu}_2(\text{Fe}, \text{Si})_{17}\text{H}_y$  [3],  $\text{Ce}_2\text{Fe}_{17}\text{H}_y$  [4] and  $\text{Ce}_2(\text{Fe}, \text{Mn})_{17}\text{H}_y$  [5–7]. When  $y \leq 2$ , the crystal lattice expansion has been observed only in the basal plane, whereas a small shrinkage along the  $c$  axis was observed with a hydrogen concentration. This effect is likely to be connected with the magnetostriction contribution to the lattice parameter magnitudes in the magnetically ordered  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x\text{H}_y$  compounds, similar to the initial  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x$  compounds [1]. It is worth stressing that a strong invar effect in the  $\text{R}_2\text{Fe}_{17}$  system is observed [10].

In figure 1, the temperature dependence of the magnetization  $M$  for three  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}\text{H}_y$  ( $y = 0, 0.15, 0.39$ ) samples taken in a field of 100 Oe are presented. The local



**Figure 2.** Temperature dependences of the magnetization in the  $\text{Lu}_2\text{Fe}_{17}$  in various magnetic fields:  $H = 0.1$  (1),  $0.6$  (2),  $1$  (3),  $1.4$  (4),  $1.8$  (5),  $2.2$  (6),  $2.6$  (7) and  $3$  kOe (8). The arrows indicate the  $\Theta_T$  and  $T_N$  values.



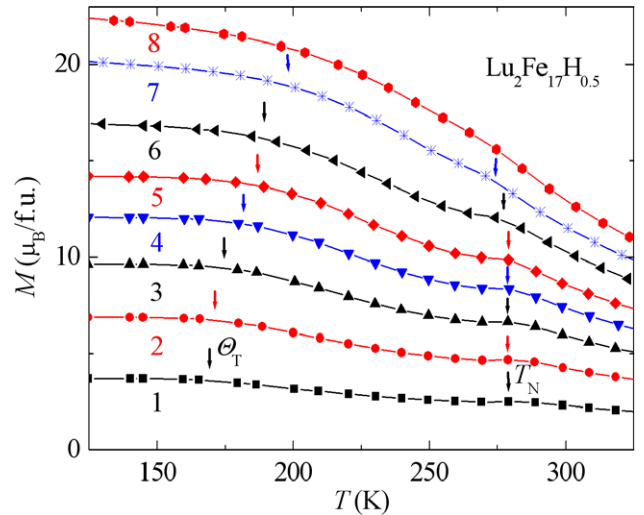
**Figure 3.** Temperature dependences of the magnetization in the  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}$  in various magnetic fields:  $H = 0.1$  (1),  $0.2$  (2),  $0.3$  (3),  $0.4$  (4),  $0.5$  (5),  $0.6$  (6) and  $0.7$  kOe (7). The arrows indicate the  $\Theta_T$  and  $T_N$  values.

maxima on the  $M(T)$  curve of the initial  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}$  alloy describes the Néel temperature  $T_N$ ; the kink on the magnetization curve at temperature  $\Theta_T$  reflects the ferromagnetic–antiferromagnetic phase transition or para–ferromagnetic transition at Curie temperature,  $T_C$ , in the hydride samples. From the figure, it appears that hydrogen destroys the antiferromagnetic ordering in  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}$  observed at high temperatures. As a result, the  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}\text{H}_y$  ( $y = 0.15, 0.39, 0.71$ ) hydrides are ferromagnets in the whole temperature range from room temperature to the lowest temperatures. The visible small bump on the  $M(T)$  curve in the  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}\text{H}_{0.39}$  sample at high temperatures is likely due to the presence of a small quantity of a second impurity phase. Similar dependences have been registered for all  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x\text{H}_y$  ( $x = 0-2, 0 < y < 3$ ) hydride samples. The temperatures of all the magnetic phase transitions in the studied  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x\text{H}_y$  ( $x = 0.5, 0.7, 2$  and  $0 < y < 3$ ) hydride samples are presented in table 1.

The  $T_C(y)$  values of ferromagnetic  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x\text{H}_y$  hydrides increase with hydrogen content. However, for a small H concentration of up to  $H/\text{f.u.} = 1$ , the magnetic transition temperatures are very close to the Néel temperature  $T_N$  of non-hydrogenated alloys. In particular,  $T_N(0)$  practically coincides with  $T_C(y)$  for  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}\text{H}_y$  hydrides. From this point of view, the  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}\text{H}_y$  is in line with the results obtained for the  $\text{Ce}_2\text{Fe}_{17}\text{H}_y$  [4] and  $\text{Ce}_2\text{Fe}_{17-x}\text{Mn}_x\text{H}_y$  hydrides [5, 6].

For several samples of  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x\text{H}_y$ , the magnetization,  $M(T)$ , measurements in different magnetic fields have been carried out. In figures 2–4, the magnetization of  $M(T)$  for  $\text{Lu}_2\text{Fe}_{17}$ ,  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}$  and  $\text{Lu}_2\text{Fe}_{17}\text{H}_{0.5}$  are presented. It is seen that both the kink at  $\Theta_T$  and the maximum at  $T_N$  are smeared out in a magnetic field, whereas  $T_N$  completely disappears, beginning with some critical value of the magnetic field above which the induced ferromagnetism exists.

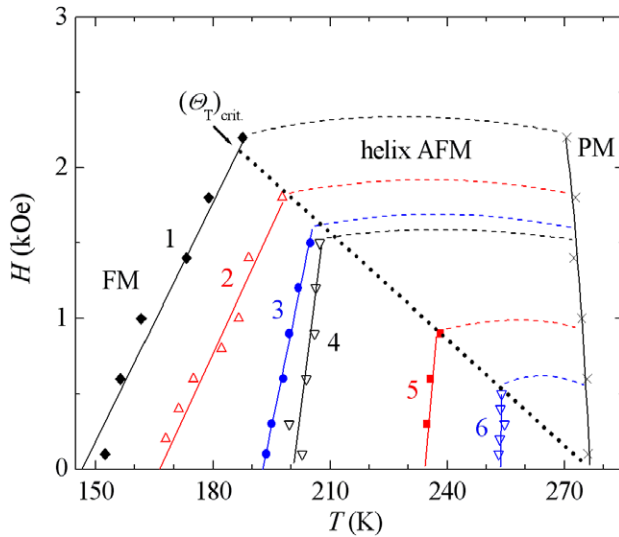
In comparing figures 1 and 3, it is obvious that the  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}$  alloy can be transferred to the ferromagnetic state in two different ways: (i) using a magnetic field of  $0.7$  kOe



**Figure 4.** Temperature dependences of the magnetization in the  $\text{Lu}_2\text{Fe}_{17}\text{H}_{0.5}$  in various magnetic fields:  $H = 0.2$  (1),  $0.4$  (2),  $0.6$  (3),  $0.8$  (4),  $1$  (5),  $1.4$  (6),  $1.8$  (7),  $2.2$  (8) and  $2.6$  (9) kOe. The arrows indicate the  $\Theta_T$  and  $T_N$  values.

or (ii) through the introduction of at least  $0.15$  H/f.u. into the lattice. The Curie temperatures for both samples are close to each other— $266$  K and  $271$  K, respectively. This indicates that the enhancement of the positive exchange interaction energy in the  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}$  lattice by  $0.15$  hydrogen atoms per formula unit is approximately equivalent to a magnetic energy of the  $3d$  magnetic moments interacting with an external magnetic field of  $0.7$  kOe.

From figures 2–4, it appears that the Néel temperature  $T_N$  diminishes, whereas  $\Theta_T$  increases with the magnetic field increasing. The dependence of  $\Theta_T$  and  $T_N$  on the magnetic field  $H$  is shown in figure 5. The data have been taken from the  $M(T)$  curves measured in several magnetic fields. The dashed lines on the diagrams show the extrapolated border



**Figure 5.** The  $H$ - $T$  magnetic phase diagrams for  $\text{Lu}_2\text{Fe}_{17}$  (1),  $\text{Lu}_2\text{Fe}_{17}\text{H}_{0.5}$  (2),  $\text{Lu}_2\text{Fe}_{17}\text{H}_{0.73}$  (3),  $\text{Lu}_2\text{Fe}_{17}\text{H}_{0.96}$  (4),  $\text{Lu}_2\text{Fe}_{16.8}\text{Mn}_{0.2}$  (5) and  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}$  (6). The thick dotted line describes the extrapolation of the critical values  $(\Theta_T)_{\text{crit.}}$  to  $H = 0$ .

of the antiferromagnetic state existence in the high magnetic fields. In figure 5, the Néel temperature  $T_N$  only for the binary  $\text{Lu}_2\text{Fe}_{17}$  compound is shown. For the other alloys, the  $T_N(H)$  dependence has the same character. In the compounds with relatively high  $\Theta_T$ , the critical field necessary to induce the ferromagnetic state is much lower. It is understandable that the interaction energy between magnetic field and magnetic moments of 3d ions gains the exchange interaction energy between magnetic 3d moments, which is too small to create the spontaneous ferromagnetic state alone.

The critical  $(\Theta_T)_{\text{crit.}}$  values for  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x\text{H}_y$  hydrides (see the thick dotted line in figure 5) transform into  $T_N$  when  $H = 0$ . This result clearly indicates that the exchange interactions in the field inducing the ferromagnetic state have an energy value comparable with those measured in the initial spontaneous antiferromagnetic state.

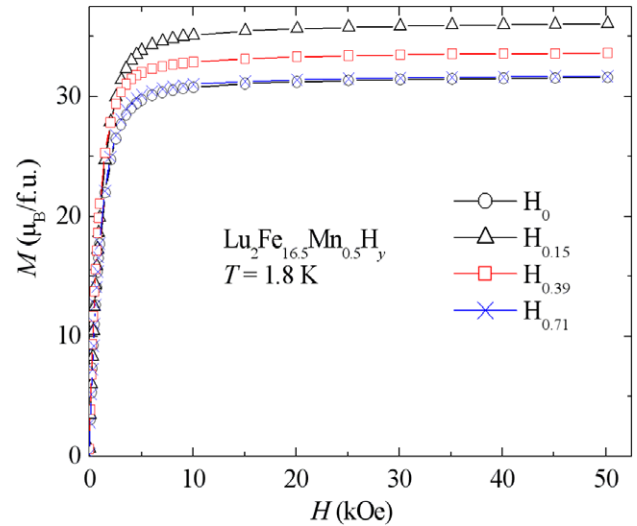
The dependence of  $\Theta_T(H)$  is somewhat different for various alloys (see figure 5). For  $\text{Lu}_2\text{Fe}_{17}$ , the slope of  $\Theta_T(H)$  is the largest, whereas for the  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x\text{H}_y$  hydrides the change of  $\Theta_T$  (with  $H$ ) decreases as  $\Theta_T$  becomes larger.

In figure 6, the field dependence of the magnetization  $M(H)$  for the powder samples of  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}\text{H}_y$  ( $y = 0$ – $0.71$  at  $T = 1.8$  K) is presented. All  $M(H)$  curves at 1.8 K for  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x\text{H}_y$  ( $x = 0$ – $2$ ,  $y = 0$ – $3$ ) have the same shape typical for ferromagnetic substances.

The value of the saturation magnetic moment  $M_{\text{sat.}}$  at 1.8 K for  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x\text{H}_y$  ( $x = 0$ – $2$ ,  $y = 0$ – $3$ ) as a function of hydrogen concentration is shown in table 1. It can be seen that  $M_{\text{sat.}}(y)$  is practically constant with H/f.u. content increasing when  $x = 0, 0.7, 2$ .

#### 4. Discussion

The magnetic properties of  $\text{Lu}_2\text{Fe}_{17}\text{H}_y$  hydrides found in our research are essentially different than those published



**Figure 6.** Demagnetization curves of the  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}$  (O),  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}\text{H}_{0.15}$  ( $\Delta$ ),  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}\text{H}_{0.39}$  ( $\square$ ) and  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}\text{H}_{0.71}$  ( $\times$ ) compounds measured on free powder samples at  $T = 1.8$  K.

in [3]. According to their study, the high temperature antiferromagnetic state disappears in binary  $\text{Lu}_2\text{Fe}_{17}\text{H}_y$  hydride at  $y = 0.8$ . Our results, however, are in accordance with the data reported in [8], where it is stated that the high temperature antiferromagnetic state with  $T_N = 372$  K survives up to  $y = 3$ . We think that the different results on the magnetic properties of  $\text{Lu}_2\text{Fe}_{17}\text{H}_y$  hydrides reported are due to the different magnetic and structural properties of the initial binary  $\text{Lu}_2\text{Fe}_{17}$  compounds [1, 3, 8]. For example, the lattice parameters of  $\text{Lu}_2\text{Fe}_{17}$  studied in [1] (see table 1) are smaller than reported in [3] ( $a = 8.3946(8)$  Å,  $c = 8.2926(9)$  Å,  $V = 506.08(12)$  Å<sup>3</sup>). These in turn are smaller than those found in [8] ( $a = 8.418$  Å,  $c = 8.295$  Å,  $V = 509.05$  Å<sup>3</sup>). In [1] and [3], the  $\Theta_T$  and  $T_N$  values for  $\text{Lu}_2\text{Fe}_{17}$  are practically the same, and  $T_N = 276$  K is somewhat larger than reported in [8] where  $T_N = 267$  K.

The temperature hysteresis of  $M$  for  $\text{Lu}_2\text{Fe}_{17}$  in [3] is about two times wider than in [1]. This type of hysteresis loop is observed only in  $\text{Lu}_2\text{Fe}_{17}$ , among the other  $\text{R}_2\text{Fe}_{17}$  compounds. Both magnetic phases (antiferromagnetic and ferromagnetic) coexist over the temperature range 130–165 K [2]. This is probably due to some non-homogeneous distribution of magnetic ions in the sample, which has been confirmed by neutron diffraction studies [2, 8, 11]. It has been clearly shown that the crystal structure of  $\text{Lu}_2\text{Fe}_{17}$  is not of the ideal  $\text{Th}_2\text{Ni}_{17}$  structure type but it is a disordered structure as proposed by Givord *et al* [12]. The equilibrium composition of the compound is shifted from the 2:17 stoichiometry to approximately 2:19, and the real structure of the compound, usually denoted as ‘ $\text{Lu}_2\text{Fe}_{17}$ ’, differs in detail from the  $\text{Th}_2\text{Ni}_{17}$  structure type due to this composition shift [2, 8, 11–13]. The determined stoichiometry of the sample studied in the current paper is close to 2:19. The shift of the composition from the stoichiometry ratio 2:17 in the direction of the 2:19 ratio is very characteristic for the  $\text{R}_2\text{Fe}_{17}$  compound with R elements from

the end of the lanthanide row and for the Y. The composition ratio 2:17 and the  $\text{Th}_2\text{Zn}_{17}$ -type structure is preferred in the iron compounds with light R lanthanide elements [7, 14]. In an ideal unit cell of the  $\text{Th}_2\text{Ni}_{17}$  type, Lu atoms should occupy two different sites, whereas Fe atoms are located in the four nonequivalent positions including ‘dumbbell’ 4f sites. Unfortunately, the  $\text{Th}_2\text{Ni}_{17}$  structure with a ratio of 2:17 appears to be unstable for iron compounds with a heavy R. Part of the Fe atoms in the dumbbell positions are substituted by R atoms, whereas some dumbbell Fe pairs occupy the vacant 4e positions. Simultaneously, the 12j (Fe) and 12k (Fe) positions are split for other nonequivalent positions [8, 12, 13]. The disorder degree in the Lu and Fe–Fe pair locations depends on the initial elements’ ratio and the synthesis conditions. Finally, the composition ratio 2:19 appears to be more stable. This atomic disorder and the presence of defects are likely to be the origin of different magnetic ( $\Theta_T$  and  $T_N$ ) results reported for  $\text{Lu}_2\text{Fe}_{17}$  and its hydride system, as was mentioned at the beginning of this section.

The observed strong enhancement of  $T_C(y)$  of the ferromagnetic  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x$  ( $x = 0.7, 2$ ) alloys under hydrogen absorption [1] is very similar to that reported for the  $\text{R}_2\text{Fe}_{17}\text{H}_y$  [4] and  $\text{Ce}_2\text{Fe}_{17-x}\text{Mn}_x\text{H}_y$  systems [5, 6]. They are explained as a result of the increase of the crystallographic unit cell volume. The enhancement of  $T_C$  observed by us in the  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x\text{H}_y$  ( $x = 0-2, y = 0-3$ ) samples can also be explained by the increase of the unit cell volume. The straight relationship between  $T_C$  and the unit cell volume is a well-known phenomenon in  $\text{R}_2\text{Fe}_{17}$ . Every time the distance between 3d ions increases, an increase in their magnetic moments value takes place [10].

An almost constant value of spontaneous magnetization  $M_{\text{sat}}(y)$  is a characteristic behavior for the hydrogenated collinear  $\text{R}_2\text{Fe}_{17}\text{H}_y$  ferri- and ferromagnetics [8, 15]. In the case of the helical ferromagnet-like  $\text{Ce}_2\text{Fe}_{17-x}\text{Mn}_x$  [5, 6], for instance, the hydrogenation visibly increases the spontaneous magnetization due to a transformation of a non-collinear magnetic structure to a collinear one by a gradual strengthening of the positive magnetic exchange interactions. The constant  $M_{\text{sat}}(y)$  value for  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x\text{H}_y$  hydrides at 1.8 K indicates that the collinear ferromagnet is indeed a magnetic ground state of this system in the range of  $x = 0-2$  and  $y = 0-3$ .

The increase of  $\Theta_T(H)$  with magnetic field in  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x\text{H}_y$  hydride samples (see figure 5) is a result of a gradual transformation of the helical antiferromagnetic structure into a collinear type in the manner observed in the  $\text{Ce}_2(\text{Fe}, \text{Mn})_{17}\text{H}_y$  hydride system [6, 7, 16]. In this light, a practically constant value of  $\Theta_T(H)$  found for  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}$  appears as non-typical for those alloys where the ‘helical antiferromagnetic–ferromagnetic’ phase transition takes place. In these circumstances, we suggest that the helical antiferromagnetic structure in  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}$  is essentially different from that in the  $\text{Lu}_2\text{Fe}_{17}$  and  $\text{Lu}_2\text{Fe}_{17}\text{H}_y$  systems in which more sophisticated magnetic structures are formed. An almost constant  $\Theta_T(H)$  value in  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}$  suggests that a mutual orientation of 3d magnetic moments is close to be collinear. It seems reasonable to make the neutron diffraction

experiments for  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}$  in the temperature range in which the antiferromagnetic state is realized.

## 5. Conclusions

The hydrogenation process of the  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x$  compounds causes an increase in the Curie temperature. The  $\text{Lu}_2\text{Fe}_{16.5}\text{Mn}_{0.5}\text{H}_y$  (with  $y \geq 0.15$ ) and  $\text{Lu}_2\text{Fe}_{17-x}\text{Mn}_x\text{H}_y$  (with  $x = 0.7$  and 2) hydrides appear to be ferromagnetic systems. It may be due to the increase of the interatomic distances, which accompanied the hydrogen absorption; the larger the interatomic distances, the more positive the exchange interactions between 3d magnetic moments. We think that the different results of the magnetic properties of the  $\text{Lu}_2\text{Fe}_{17}\text{H}_y$  hydrides reported are due to the tendency of the initial binary  $\text{Lu}_2\text{Fe}_{17}$  compound to form the crystallographically not sufficiently homogeneous phases.

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