

## Hyperfine fields at the anion sites in $\text{USb}_{1-x}\text{Te}_x$ and $f$ - $p$ hybridization

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We report a low-temperature (4.2 K)  $^{121}\text{Sb}$  and  $^{125}\text{Te}$  Mössbauer study of the  $\text{USb}_{1-x}\text{Te}_x$  solid solutions. Large transferred hyperfine fields are observed at the ligand sites in the magnetically ordered state of the compounds. The hyperfine field is found to be positive and isotropic in the ferromagnetic samples. The large anisotropic contribution to the hyperfine field observed in the antiferromagnetic type I and type IA phases is interpreted as resulting from the spin polarization of the ligand  $5p$  states induced via strong hybridization with the uranium  $5f$  valence band.

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### I. INTRODUCTION

The exotic physical properties of actinide compounds are mainly coming from  $5f$  hybridization with both on-site and neighboring ligand states. The central question concerns the nature of the  $5f$  electrons, localized as in  $4f$  compounds, itinerant such as  $3d$  electrons or between these two extreme conditions. During the past three decades special attention has been paid to uranium monpnictides UX ( $X=\text{P, As, Sb, Bi}$ ) and uranium monochalcogenides UY ( $Y=\text{S, Se, Te}$ ) and their solid solutions, which crystallize with the simple NaCl-type structure.<sup>1</sup>

USb which shows an antiferromagnetic transition toward a type I-triple  $k$  structure at 214 K (Ref. 2) was generally considered as a typical example of localized  $5f$  electrons: their localized nature was concluded from photoelectron spectroscopy (PES) (Ref. 3) features with a  $5f^2$  final state multiplet structure below the Fermi energy ( $E_F$ ), the observation of crystal field excitations by neutron scattering,<sup>4</sup> the small electronic specific heat coefficient ( $\gamma\sim 4$  mJ/mol K<sup>2</sup>) (Ref. 5), and the large ordered uranium moment<sup>2</sup> ( $2.85\mu_B$ ).

On the other hand, UTe which orders ferromagnetically at 104 K exhibits more intricate properties.<sup>1</sup> Neutron scattering shows magnetic excitations in the ordered phase, but no crystal field level in the paramagnetic phase.<sup>6</sup> Resistivity data<sup>7</sup> suggest that UTe is a dense Kondo system in agreement with the strong interaction between the localized  $5f$  and itinerant ( $6d$ ) conduction electrons as inferred from the PES measurements<sup>3</sup> and the negative polarization of the conduction electrons. Intermediate valence behavior is invoked from the observed negative value of the  $c_{12}$  elastic constant.<sup>8</sup>

The strong anisotropic exchange interactions as well as the high-ordering temperatures observed in both USb and UTe are ascribed either to two-ion anisotropic interactions based on the Coqblin-Schrieffer model<sup>9</sup> or to anisotropic superexchange interactions.<sup>2</sup> The second possibility advocated by Kasuya<sup>10</sup> and referred as the  $f$ - $p$  mixing model is also advanced to explain the trend of the magnetic anisotropy in the monochalcogenide series.<sup>11</sup> It implies the semimetallic properties of the compounds which lead to strong  $p$ - $f$  hybridization, i.e., mixing between the  $5f$  electrons located just

below  $E_F$  and the anion  $p$  band, which must touch the Fermi level.

The magnetic phase diagram of the  $\text{USb}_{1-x}\text{Te}_x$  solid solutions has been determined both by magnetization and single crystal neutron diffraction (Fig. 1). At low temperature the magnetic structure changes with increasing tellurium concentration from triple- $k$  antiferromagnetic type I to triple- $k$  antiferromagnetic type IA and then to the ferromagnetism (Fig. 2) with, in addition, the occurrence between type I and type IA of an intermediate ferrimagnetic phase.<sup>2</sup> The uranium moments which have always a  $\langle 111 \rangle$  easy axis maintain a rather large value as in USb ( $2.85\mu_B$ ) up to  $x=0.5$  and then decrease for high-Te concentration down to  $2.25\mu_B$  in UTe.<sup>2</sup> Some insights on the evolution of the electronic structure along the  $\text{USb}_{1-x}\text{Te}_x$  series is provided by PES measurements.<sup>3</sup> A progressive broadening of the  $f$ - $d$  hybridized bands and of the anion  $s$ - $p$  derived bands is observed with increasing Te content. In addition, their main features are shifted to higher binding energies.

Recently high resolution angle resolved PES measurements (ARPES) lead to reconsider some of our views on the electronic structures of USb and UTe.<sup>12–14</sup> Indeed, both compounds exhibit hybridized  $5f$  states with dual character. The dispersive character of the  $5f$  bands is inconsistent with a localized multiplet interpretation. The main difference between USb and UTe is that one of the narrow  $5f$  band crosses  $E_F$  in the latter compound. The claim that USb has a metallic band structure shed some doubt on the relevance of the  $p$ - $f$  mixing model for uranium monpnictides and monochalcogenides.<sup>12</sup> Clearly more experimental and theoretical studies are still needed to determine the extend of hybridization or localization of the  $5f$  electrons in these materials.

Here we report on  $^{121}\text{Sb}$  and  $^{125}\text{Te}$  Mössbauer experiments in the  $\text{USb}_{1-x}\text{Te}_x$  solid solutions. The Mössbauer data provide the transferred hyperfine interaction at the nominally diamagnetic anions ( $\text{Sb}^{3-}$ ,  $\text{Te}^{2-}$ ). This information offers the possibility to follow the evolution of the magnetic interactions, the type of magnetic ordering (antiferromagnetism toward ferromagnetism) and the electronic structure when Sb is replaced by Te. We found a strong anisotropic contribution to the hyperfine field in the antiferromagnetic phases which

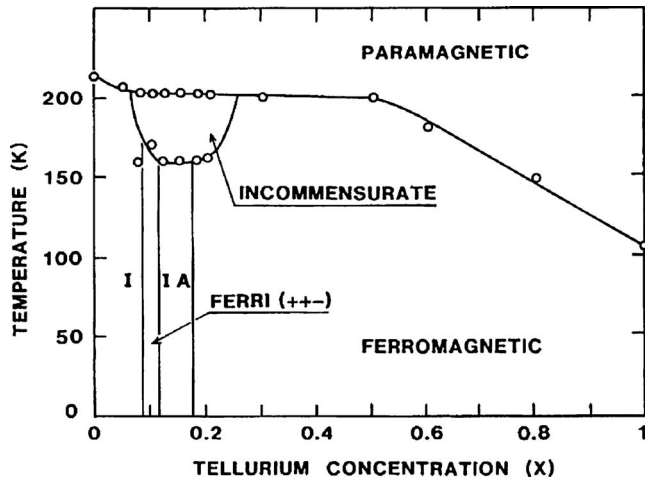


FIG. 1. Magnetic phase diagram of the  $\text{USb}_{1-x}\text{Te}_x$  solid solutions as a function of temperature and tellurium concentration [adapted from Rossat-Mignod *et al.* (Ref. 2)]

is attributed to the  $f$ - $p$  hybridization. In the ferromagnetic phases, the positive and isotropic hyperfine field due to the polarization of the conduction electrons and to the  $f$ - $s$  hybridization, is shown to decrease almost linearly with the Te concentration.

## II. EXPERIMENTAL METHODS

The powdered  $\text{USb}_{1-x}\text{Te}_x$  ( $x=0, 0.15, 0.20, 0.30, 0.50, 0.60, 0.80,$  and  $1$ ) samples for the Mössbauer studies are obtained by crushing single crystals grown by the mineralization<sup>15</sup> technique at ETH in Zürich and characterized previously by various techniques.<sup>1</sup> The absorber thicknesses of the samples are typically around  $10 \text{ mg/cm}^2$  of natural Sb or Te. The source for the  $37.2 \text{ keV}$  gamma rays of the  $5/2-7/2$  transition of  $^{121}\text{Sb}$  is  $660 \mu\text{Ci}$  of  $\text{Ca}^{121\text{m}}\text{SnO}_3$ . The gamma rays for the  $35.5 \text{ keV}$  resonance of  $^{125}\text{Te}$  ( $1/2-3/2$  transition) are produced by a  $2 \text{ mCi}$   $^{125}\text{Sb}/\text{Cu}$  source. Both the sources and the absorbers are kept at a temperature of  $4.2 \text{ K}$  during the measurements. The gamma rays are detected using a solid state Ge detector. For the in-field  $^{125}\text{Te}$  measurements, the UTe absorber (a powder free to rotate) is located in the center of a superconducting coil producing a field of  $50 \text{ kOe}$  while the  $^{125}\text{Sb}/\text{Cu}$  source is held in zero magnetic field. The data are directly fitted to the hyperfine parameters by constraining the relative absorption energies and intensities of the Lorentzian lines to theoretical values.

## III. RESULTS AND DISCUSSION

Typical Mössbauer spectra of  $^{121}\text{Sb}$  and  $^{125}\text{Te}$  in  $\text{USb}_{1-x}\text{Te}_x$  obtained at  $4.2 \text{ K}$  are shown in Fig. 3. The spectral resolution is considerably better for the  $^{121}\text{Sb}$  resonance owing to its smaller natural linewidth ( $2.10 \text{ mm/s}$  vs  $5.21 \text{ mm/s}$  for  $^{125}\text{Te}$ ).<sup>16</sup> The best fits (solid lines in Fig. 3) to the data are pure magnetic interactions as expected from the lack of asymmetry in the spectra. The observation of vanishing quadrupolar effects is not surprising: the anion  $5p$  bands are almost completely filled and the triple- $k$ -type structures (I

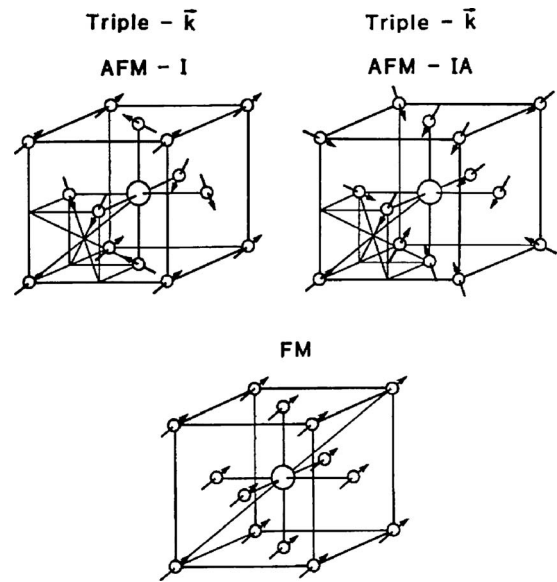


FIG. 2. Low temperature magnetic structures observed in the  $\text{USb}_{1-x}\text{Te}_x$  solid solutions. Antiferromagnetic (AFM) triple- $k$  type I ordering ( $x < 0.09$ ), AFM triple- $k$  type IA ordering ( $0.12 < x < 0.17$ ), ferromagnetic (FM) ordering ( $x > 0.18$ ). The uranium magnetic moments point along  $\langle 111 \rangle$  directions in all magnetic structure types. The Sb or Te anions (large circles) have an octahedral environment of six nearest U—neighbors [adapted from Rossat-Mignod *et al.* (Ref. 2)].

and IA) retain cubic symmetry while only a rhombohedral lattice distortion<sup>1</sup> is detected in the ferromagnetic phases. Figure 4 presents the variation of the magnetic hyperfine field ( $H_{\text{hf}}$ ) at the anion nuclei ( $^{121}\text{Sb}$  and  $^{125}\text{Te}$ ) as a function of the tellurium concentration ( $x$ ). For  $\text{USb}$  ( $x=0$ ), the field is found to be  $171(3) \text{ kOe}$  in good agreement with the previous data.<sup>17</sup> For  $x=0.15$ , i.e., for a sample whose magnetic structure at  $4.2 \text{ K}$  is of type IA, the  $^{121}\text{Sb}$  hyperfine field raises to a value of  $207(2) \text{ kOe}$ . A further jump of  $H_{\text{hf}}$  ( $^{121}\text{Sb}$ ) is observed when ferromagnetic order sets in [ $H_{\text{hf}} = 256(2) \text{ kOe}$  for  $x=0.2$ ]. A same trend shows up for the  $^{125}\text{Te}$  hyperfine field at the transition from type IA to ferromagnetism [ $162(4)$  and  $212(4) \text{ kOe}$  for  $x=0.15$  and  $0.2$ , respectively]. For  $x > 0.2$ , i.e., in the ferromagnetic state, both  $^{121}\text{Sb}$  and  $^{125}\text{Te}$  hyperfine fields decrease almost linearly when the Te content increases. The  $^{125}\text{Te}$  hyperfine field of  $128(2) \text{ kOe}$  found for UTe agrees well with the published value [ $130(5) \text{ kOe}$ ] for a slightly U deficient sample ( $\text{U}_{0.9}\text{Te}$ ).<sup>18</sup> Figure 5 shows the  $^{125}\text{Te}$  Mössbauer spectra of UTe recorded in zero external field and in a field of  $50 \text{ kOe}$  applied parallel to the radiation propagation axis. The zero-field spectrum is fitted to a pure magnetic interaction as the data in Fig. 3. The in-field Mössbauer spectrum is analyzed under the assumption that the loose UTe microcrystals reorient along the applied field ( $H_{\text{app}}$ ) in such a way that the saturation magnetization of each grain remains parallel to the  $\langle 111 \rangle$  easy axis of this highly anisotropic material. Thus the spectrum is fitted assuming a superposition of Lorentzian lines with equal line width and intensity ratio  $3:0:1:1:0:3$ . Depending on the sign of  $H_{\text{hf}}$ , the effective magnetic field,  $\vec{H}_{\text{eff}} = \vec{H}_{\text{hf}} + \vec{H}_{\text{app}}$ , is either parallel or antiparallel to  $H_{\text{app}}$ .  $H_{\text{eff}}$

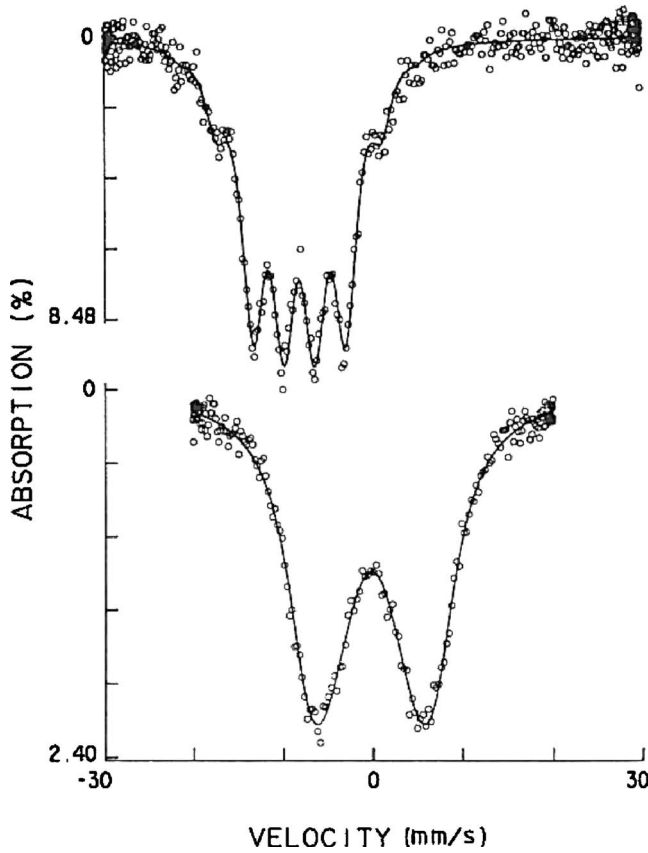


FIG. 3.  $^{121}\text{Sb}$  (top) and  $^{125}\text{Te}$  (bottom) Mössbauer spectra of  $\text{USb}_{0.5}\text{Te}_{0.5}$  taken at 4.2 K. The solid lines are the best fits to the data points assuming pure magnetic interactions.

is found to be 171(4) kOe, i.e., close to the value [178(3) kOe] expected for a hyperfine field parallel to the applied field. This implies that the hyperfine field is positive and isotropic.

The  $^{121}\text{Sb}$  isomer shift increases only slightly with the Te content [ $-8.22(4)$  mm/s for  $x=0$  to  $-8.07(6)$  mm/s vs  $\text{CaSnO}_3$  for  $x=0.8$ ]. These values are typical of those found in other monoantimonides.<sup>19</sup> Since  $\Delta\langle r^2 \rangle$ , the change of the mean square nuclear charge radius, is negative for  $^{121}\text{Sb}$  this increase corresponds to a decrease of the electron density at the  $^{121}\text{Sb}$  nuclei ascribed to an enhanced shielding effect exerted by filling the Sb  $5p$  band. This observation supports the  $p$ - $f$  mixing model. No significant change of the  $^{125}\text{Te}$  isomer shift was observed along the  $\text{USb}_{1-x}\text{Te}_x$  solid solutions owing to the fact that  $\Delta\langle r^2 \rangle(^{125}\text{Te}) \sim -0.1\Delta\langle r^2 \rangle(^{121}\text{Sb})$ . This isomer shift value of  $-0.17(5)$  mm/s vs  $^{125}\text{Sb}/\text{Cu}$  compares to those observed in rare earth monotellurides.<sup>20</sup>

The magnetic hyperfine field acting at the nuclei of the nominally diamagnetic Sb or Te atoms, in the ordered state of the  $\text{USb}_{1-x}\text{Te}_x$  solid solutions, arises from the finite spin density at the ligand site produced by the uranium  $5f$  spin via the exchange interactions. Two main mechanisms contribute to the transferred hyperfine field: (i) the conduction electron polarization through the long range Ruderman-Kittel-Kasuya-Yosida (RKKY) interaction,<sup>21,22</sup> and (ii) the mixing of the  $5f$  band with the ligand valence  $5s$ - $p$  band.<sup>23</sup> Writing explicitly the contributions to the hyperfine field in terms of

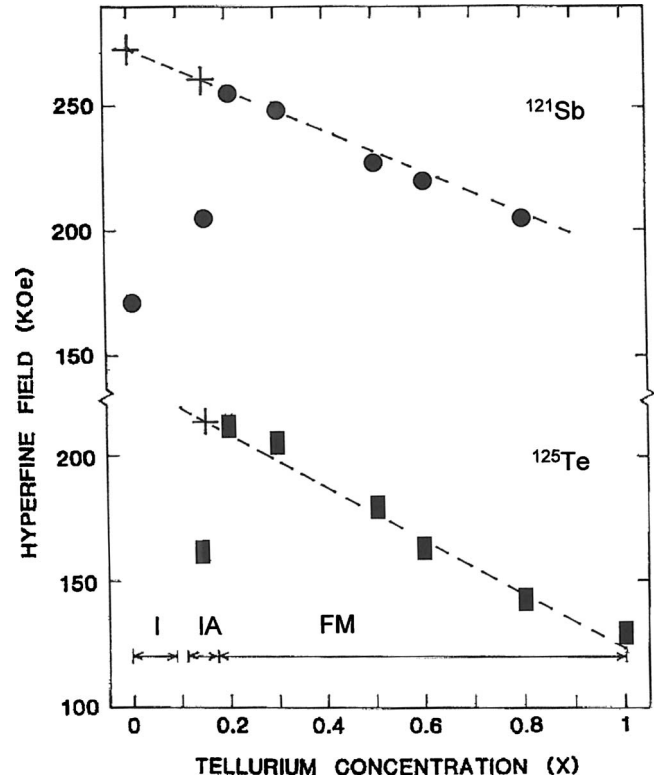


FIG. 4. Transferred hyperfine fields (4.2 K) at the anion nuclei ( $^{121}\text{Sb}$  and  $^{125}\text{Te}$ ) in the  $\text{USb}_{1-x}\text{Te}_x$  solid solutions as a function of the tellurium concentration ( $x$ ). The crosses are an estimate of the hyperfine fields in the hypothetical ferromagnetic state of  $\text{USb}$  and  $\text{USb}_{0.85}\text{Te}_{0.15}$ . Their values are obtained from a linear extrapolation of the fields observed in the ferromagnetic phases ( $x \geq 0.2$ )

spin density transfer along the U-Sb(Te) bond direction  $\alpha$ , the components of the hyperfine field for a single U-Sb(Te) bond can be expressed as<sup>24</sup>

$$H_{\alpha}^{\text{hf}} = \{H_{\text{iso}} + H_{\text{an}}\} \frac{m_{\alpha}}{m},$$

$$H_{\beta,\gamma}^{\text{hf}} = \left\{ H_{\text{iso}} - \frac{1}{2} H_{\text{an}} \right\} \frac{m_{\beta,\gamma}}{m},$$

where

$$H_{\text{iso}} = H_{\text{cep}}(g_J - 1)J \frac{m}{m_{f.i.}} + \frac{8\pi}{3} \mu_B f_{5s} \rho(0) - \kappa \mu_B \langle r^{-3} \rangle f_{5p},$$

$$H_{\text{an}} = -\frac{4}{5} \mu_B \langle r^{-3} \rangle f_{5p}. \quad (1)$$

$H_{\text{iso}}$  is an isotropic contribution whose first term arises from the  $6d$ - $7s$  conduction electron polarization, the second term is a contact field due to the unpaired spin density ( $f_{5s}$ ) transferred into the Sb(Te) $5s$  band through  $f$ - $s$  hybridization, the third term is a core polarization field due to the spin density  $f_{5p}$  in the ligand  $5p$  band (the field produced by an unpaired  $p$  electron,  $\kappa \mu_B \langle r^{-3} \rangle$ , was estimated to amount  $-280$  kOe).<sup>25</sup>  $H_{\text{cep}}$  depend on the conduction electron susceptibility as well as on the nature of the conduction electrons ( $s, d$ ) and on the

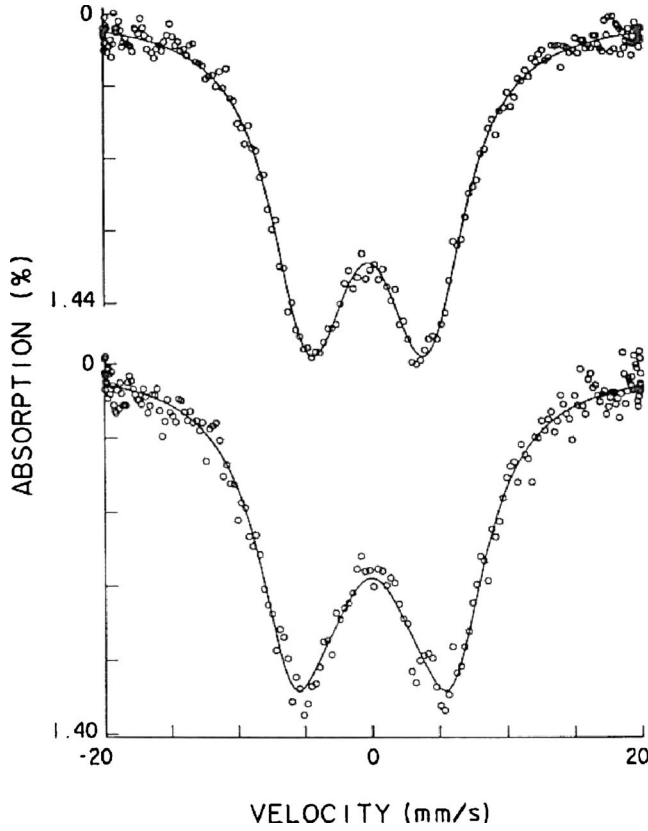


FIG. 5.  $^{125}\text{Te}$  Mössbauer spectra of UTe taken at 4.2 K in zero applied field (top) and in a longitudinal applied field of 50 kOe (bottom). The solid lines are the best fits to the data points (see text).

electronic structure of the diamagnetic atom,  $g_J$  is the Landé factor of the  $\text{U}^{3+}$  ions with angular momentum  $J$ ,  $m$ , and  $m_{f.i.}$  are the U magnetic moment in the ordered state and in the free ion, respectively.  $\rho(0)$  is the  $5s$  electron density at the ligand nucleus.  $H_{\text{an}}$  is an anisotropic contribution viewed as a spin dipolar field arising from the spin density ( $f_{5p}$ ) induced by the  $f$ - $p$  hybridization.  $\langle r^{-3} \rangle$  is the average radial distribution of the ligand  $5p$  electrons.  $m_{\alpha,\beta,\gamma}$  are the projections of the uranium moment,  $m \parallel \langle 111 \rangle$ , along the orthogonal system of axes ( $\alpha, \beta, \gamma$ ).

Considering now only the six nearest-neighbors U atoms of an Sb or Te atom, the total hyperfine field is obtained by summation over the six equivalent and independent U-Sb(Te) bonds. The components of the hyperfine field along the crystal [100], [010], and [001] axes are given by the following expressions for type I, type IA, and ferromagnetic structures (see Fig. 2):

Type I structure,

$$H_{\text{hf}}[100] = \{-2H_{\text{iso}} - 2H_{\text{an}}\} \frac{\sqrt{3}}{3}$$

$$H_{\text{hf}}[010] = \{-2H_{\text{iso}} - 2H_{\text{an}}\} \frac{\sqrt{3}}{3}$$

$$H_{\text{hf}}[001] = \{-2H_{\text{iso}} + 4H_{\text{an}}\} \frac{\sqrt{3}}{3}. \quad (2a)$$

Type IA structure,

$$H_{\text{hf}}[100] = \{-4H_{\text{iso}} - H_{\text{an}}\} \frac{\sqrt{3}}{3}$$

$$H_{\text{hf}}[010] = \{-4H_{\text{iso}} - H_{\text{an}}\} \frac{\sqrt{3}}{3}$$

$$H_{\text{hf}}[001] = \{-4H_{\text{iso}} + 2H_{\text{an}}\} \frac{\sqrt{3}}{3} \quad (2b)$$

Ferromagnetic structure,

$$H_{\text{hf}}[100] = H_{\text{hf}}[010] = H_{\text{hf}}[001] = \{6H_{\text{iso}}\} \frac{\sqrt{3}}{3}. \quad (2c)$$

It follows that  $H_{\text{hf}}(\text{type I}) = \{4H_{\text{iso}}^2 + 8H_{\text{an}}^2\}^{1/2}$ ,  $H_{\text{hf}}(\text{type IA}) = \{16H_{\text{iso}}^2 + 2H_{\text{an}}^2\}^{1/2}$ , and  $H_{\text{hf}}(\text{ferro}) = 6H_{\text{iso}}$ .

Two remarks can already be made from the above expressions: (i) sole the isotropic term contributes to the hyperfine field for the ferromagnetic case, in agreement with the conclusion obtained from the applied field measurement in UTe, (ii) the ratios of the isotropic contributions to the hyperfine field for the type I, type IA, and ferromagnetic cases are 1:2:3, respectively. Comparison with the experimental data clearly indicates that the anisotropic contribution is important in the antiferromagnetic phases.

As shown in Fig. 4,  $H_{\text{hf}}$  decreases almost linearly with the tellurium content in the ferromagnetic phases ( $x \geq 0.2$ ). Assuming that this linearity still hold for  $x < 0.2$ , one could, by extrapolation, estimate the hyperfine fields which should be observed in the hypothetical ferromagnetic states of USb (273 kOe) and  $\text{USb}_{0.85}\text{Te}_{0.15}$  (260 and 218 kOe for  $^{121}\text{Sb}$  and  $^{125}\text{Te}$  nuclei, respectively). It is thus possible to evaluate the evolution of the isotropic and anisotropic contributions to the hyperfine field along the  $\text{USb}_{1-x}\text{Te}_x$  solid solutions (Table I).

$H_{\text{iso}}$  for both ligands is shown to decrease when Sb is replaced by Te. This decrease is much faster than the one observed for the uranium ordered moment (i.e.,  $2.64\mu_B$  for  $x=0.2$  and  $2.25\mu_B$  for  $x=1$ ) This behavior can arise from the trend of the conduction electron polarization<sup>26</sup> which changes from  $-0.06\mu_B$  for  $x=0.2$  to  $-0.34\mu_B$  for  $x=1$ , and from the *opposite sign* of the terms contributing to  $H_{\text{iso}}$ . On the other hand,  $H_{\text{an}}$ , whose contribution can only be measured in the antiferromagnetic phases, increases when the magnetic structure changes from type I ( $x=0$ ) to type IA ( $x=0.15$ ). From the values of  $H_{\text{an}}$  given in Table I and the computed  $\langle r^{-3} \rangle$  factors,<sup>27</sup> one can estimate the spin density  $f_{5p}$  in USb (7.8%) and in  $\text{USb}_{0.85}\text{Te}_{0.15}$  (12.2% and 6.8% at the Sb and Te sites, respectively). These rather large spin densities indicate that the  $f$ - $p$  hybridization plays an important role in the delocalization process of the  $5f$  electrons and in turn on the electronic and magnetic properties of the uranium monpnictides and monochalcogenides. The  $f$ - $p$  hybridization is also at the origin of the observation of unexpectedly large enhancements of the magnetic scattering

TABLE I. Values of  $H_{\text{iso}}$  and  $H_{\text{an}}$  (in kOe), deduced from the analysis of the hyperfine field data at the  $^{121}\text{Sb}$  and  $^{125}\text{Te}$  ligand site, as a function of the Te content ( $x$ ) in the  $\text{USb}_{1-x}\text{Te}_x$  solid solutions.  $H_{\text{an}}$  can only be measured in the antiferromagnetic phases, i.e., for samples with  $x < 0.2$ .

$x$	$^{121}\text{Sb}$		$^{125}\text{Te}$	
	$H_{\text{iso}}$	$H_{\text{an}}$	$H_{\text{iso}}$	$H_{\text{an}}$
0	45.5	51.2		
0.15	43.3	80.1	36.3	50.8
0.20	42.7		35.3	
0.30	41.4		34.1	
0.50	38.0		29.8	
0.60	36.8		27.3	
0.80	34.2		23.5	
1			21.3	

intensities or dichroic signals at the  $K$  edges of nominally nonmagnetic anions in actinide compounds<sup>28–31</sup> like, e.g.,  $\text{UGa}_3$  or  $\text{US}$ .

The  $H_{\text{an}}$  value measured in  $\text{USb}$  (Table I) may be compared with the value deduced for  $\text{CeSb}$  from Knight-shift measurements in the paramagnetic state<sup>32</sup> and from  $^{121}\text{Sb}$  Mössbauer data<sup>33</sup> at 4.2 K where  $\text{CeSb}$  orders in the antiferromagnetic type IA structure.<sup>34</sup> The  $^{121}\text{Sb}$  hyperfine coupling constant was estimated to be  $35.5 \text{ kOe}/\mu_B$ .<sup>32</sup> Assuming that it will not change in the magnetically ordered state, the hyperfine field expected for  $\text{CeSb}$  in the ferromagnetic state should be 73 kOe, taking an ordered Ce moment of  $2.05\mu_B$ .<sup>34</sup> Knowing that the hyperfine field in the antiferromagnetic IA state is 64 kOe (Ref. 33) and using Eqs. (2c),  $H_{\text{an}}$  in  $\text{CeSb}$  is estimated to amount about 28 kOe. Therefore it appears that the  $f$ - $p$  hybridization is less effective in  $\text{CeSb}$  than in  $\text{USb}$ .

#### IV. SUMMARY AND CONCLUSIONS

We have studied the electronic and magnetic properties of the  $\text{USb}_{1-x}\text{Te}_x$  solid solutions by  $^{121}\text{Sb}$  and  $^{125}\text{Te}$  Mössbauer spectroscopies. The transferred hyperfine field at the anion nuclei is found to be isotropic in the ferromagnetic phases while a large anisotropic contribution is observed in the antiferromagnetic type I and type IA phases. This anisotropic contribution, which probes the ligand  $5p$  spin density is directly connected to the strength of the hybridization of the  $5p$  states with the uranium  $5f$  valence band. Therefore, any realistic band structure model has to reproduce the polarization of the  $5sp$  band of the anions. Moreover, uranium monopnictides and monochalcogenides are model materials which should be re-examined by high-resolution energy-dependent ARPES measurements to precise the positions of the  $5f$  band features versus the Fermi energy and the location of the broad  $5sp$  band. Transferred field measurements at the ligand site either by nuclear magnetic resonance (NMR) or Mössbauer spectroscopy complement nicely ligand magnetic x-ray scattering data or x-ray magnetic circular dichroism experiments. The magnitude of the signal at the ligand  $K$ -edge is expected to scale with the anisotropic contribution ( $H_{\text{an}}$ ) to the hyperfine field. Recent studies on  $\text{NpCoGa}_5$  have shown that it is the case.<sup>30,35</sup> The recent extension of the nuclear forward scattering (NFS) technique to the  $^{121}\text{Sb}$  and  $^{125}\text{Te}$  Mössbauer isotopes<sup>36,37</sup> will allow to study  $\text{USb}$  and  $\text{UTe}$  under high applied pressures (at least up to 30 GPa). This will provide unique insights on the pressure dependence of the transferred hyperfine field and its interplay with the evolution of the magnetic properties of  $\text{USb}$  and  $\text{UTe}$  under pressure.<sup>38,39</sup>

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<sup>1</sup>See *Handbook on the Physics and Chemistry of the Actinides*, edited by A. J. Freeman and G. H. Lander (North-Holland, Amsterdam, 1984/1985), Vols. 1–2.

<sup>2</sup>See J. Rossat-Mignod, G. H. Lander, and P. Burlet, in Ref. 1, Vol. 1, p. 415.

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