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Ikram Dhouib, Philippe Guionneau, Tahar Mhiri, Zakaria Elaoud. Crystal structure, thermal behavior and vibrational studies of tetraethylammonium dihydrogenarsenate bis-arsenic acid  $[(C_2H_5)_4N].[H_2AsO_4].[H_3AsO_4]_2$ . European Journal of Chemistry, 2014, 5 (3), pp.388-393. 10.5155/eurjchem.5.3.388-393.1038 . hal-00986960

**HAL Id: hal-00986960**

**<https://hal.science/hal-00986960>**

Submitted on 18 Apr 2024

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# Crystal structure, thermal behavior and vibrational studies of tetraethylammonium dihydrogenarsenate *bis*-arsenic acid $[(C_2H_5)_4N].[H_2AsO_4].[H_3AsO_4]_2$

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## ARTICLE INFORMATION



DOI: 10.5155/eurjchem.5.3.388-393.1038

Received: 26 February 2014

Received in revised form: 13 March 2014

Accepted: 13 March 2014

Online: 30 September 2014

## KEYWORDS

Arsenic acid  
Crystal structure  
Organic compounds  
Raman spectroscopy  
Infrared spectroscopy  
Differential scanning calorimetry

## ABSTRACT

An organic-inorganic hybrid compound of tetraethylammonium dihydrogenarsenate *bis*-arsenic acid salts of formula  $[(CH_3CH_2)_4N].[H_2AsO_4].[H_3AsO_4]_2$  (TEAs) were grown by the slow evaporation and characterized by means of single crystal X-ray diffraction, thermal analysis, FT-IR and Raman spectroscopy. This compound crystallize in the space groups *Cc* with unit cell parameters,  $a = 20.105(2) \text{ \AA}$ ;  $b = 7.342(4) \text{ \AA}$ ;  $c = 15.292(2) \text{ \AA}$ ,  $\gamma = 115(4)^\circ$ ,  $Z = 4$ ,  $R = 0.07$ . The structure has solved using direct methods and refined by least-squares analysis. In this case, the structure consists of infinite parallel two-dimensional planes built of mutually  $H_2AsO_4^-$ ,  $H_3AsO_4$  tetrahedra connected by strong O-H...O hydrogen bonding. The thermoanalytical properties were studied using TG of TEAs method in the temperature ranges from 300 to 440 K for this hygroscopic sample. DSC measurement was carried out in the temperature range from 305 to 425 K.

## 1. Introduction

The combination of organic molecules and inorganic materials was the starting point for the development of new hybrid compounds, with desired physical and chemical properties [1,2]. These compounds have attracted great attention because of their unique opportunity to combine the remarkable features of organic compounds with those of inorganic materials. Their applications have been explored and reported in various fields, such as electronic [3,4], optical [5,6] magnetic [7,8] and ferroelectric [9,10].

In organic-cation monophosphate/monoarsenate, the phosphate/arsenate anions are interconnected by strong hydrogen bonds so as to build infinite networks with various geometries: ribbons [11], chains [12,13], two-dimensional network [14,15], and three-dimensional network [16].

On the other hand, there is still growing interest in the study of crystal containing tetra-alkylammonium cations of the general formula  $(C_nH_{2n+1})_4N^+$  such as  $(CH_3)_4N^+$ ,  $(C_2H_5)_4N^+$  and  $(C_3H_7)_4N^+$ . The specific geometry of these cations can generate supramolecular networks in one, two or three dimensions. Recently, numerous tetra-ethylammonium derivatives structural and vibrational studies have been published [17-18].

However, in conjunction with some recent works on these hybrids compounds, the crystal structure and vibrational studies of many organic-inorganic crystals have been investigated in our laboratory [19-21]. The present work deals with the growth, single crystal X-ray diffraction (XRD) study, thermal analysis and the detailed vibrational spectral analysis of a new organic-inorganic: tetraethylammonium dihydrogen monoarsenate *bis*-arsenic acid (TEAs).

## 2. Experimental

## 2.1. Synthesis

The crystal of the title compound, TEAs, is prepared by slow evaporation at room temperature of an aqueous solution of arsenic acid  $H_3AsO_4$ , and tetraethylammonium hydroxide  $[CH_3CH_2]_4NOH$  in the stoichiometric ratio (3:1) and mixed well using a magnetic stirrer to ensure homogenous concentration in the entire volume of the solution. The solutions which allowed evaporating at room temperature a few days until colorless parallel piped shaped monocrystals of TEAs were formed. The reaction scheme involved in the formation of complex compound is given in (1).

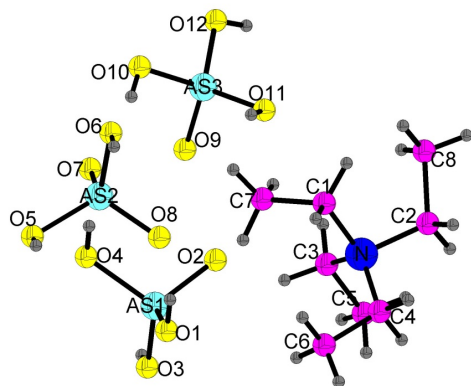


Figure 1. The asymmetric unit of  $[(\text{CH}_3\text{CH}_2)_4\text{N}] (\text{H}_2\text{AsO}_4) (\text{H}_3\text{AsO}_4)_2$ .



## 2.2. X-ray single crystal structure determination

The structure of TEAs was determined by the X-ray single crystal diffraction method. In each case, a suitable crystal was selected under a polarizing microscope and mounted on a thin glass fiber. The unit cell dimensions of salt was measured and refined using indexation of diffraction markings collected with a Kappa CAD4 automated four-circle diffractometer (graphite-monochromated MoK $\alpha$  radiation,  $\lambda = 0.71073 \text{ \AA}$ ). Peak search, centering, indexing and least squares refinement routines led to a monoclinic unit cell for the compound. The final unit cell constants were determined by a least-squares fit of 5066 reflections. The crystal structure was solved by direct methods using SHELXS-97 [22] and difference Fourier synthesis. All the hydrogen positions were geometrically and affined located.

## 2.3. Spectroscopic measurements

The Fourier transform infrared (FT-IR) spectrum of TEAs was recorded in the range 4000-400  $\text{cm}^{-1}$ , with samples in KBr pellets using Perkin-Elmer FT-IR spectrometer. The resolution of the spectrum is  $\pm 2 \text{ cm}^{-1}$ . The Fourier transform Raman (FT-Raman) spectrum of the same compound was recorded using Horiba Jobin Yvon LabRAM HR 800 Dual spectrophotometer. The incident laser excitation is 632 nm. The scattered light was collected at the angle of  $180^\circ$  in the region 3600-50  $\text{cm}^{-1}$  and the resolution was set up to  $2 \text{ cm}^{-1}$ .

## 3. Results and discussion

### 3.1. Structural analysis of TEAs

The crystals of the title compound belong to the centrosymmetric Cc space group of the monoclinic system, with  $Z = 4$ . The lattice parameters are listed in Table 1. The bond lengths and angles are collected in Table 2.

The asymmetric unit is composed of one  $[\text{H}_2\text{AsO}_4]^-$  anion, two neutral arsenic acid  $[\text{H}_3\text{AsO}_4]$  and one  $[(\text{CH}_3\text{CH}_2)_4\text{N}]^+$  cation (Figure 1). The structure consists of infinite parallel two-dimensional planes built of mutually  $[\text{H}_2\text{AsO}_4]^-$ ,  $[\text{H}_3\text{AsO}_4]$  tetrahedra and  $(\text{CH}_3\text{CH}_2)_4\text{N}^+$  cations, the projection along the  $b$  axis of the atomic arrangement is depicted in Figure 2.

The coordination of arsenic atoms is tetrahedral with As-O distances and O-As-O angles in the ranges (1.622(13); 1.796(7)  $\text{\AA}$ ); (1.556(14); 1.739(10)  $\text{\AA}$ ); (1.634(10); 1.718(8)  $\text{\AA}$ ); (107.7(5); 113.5(6) $^\circ$ ); (103.1(6); 114.8(6) $^\circ$ ) and (103.0(5); 115.8(5) $^\circ$ ) for  $[\text{H}_3\text{As}(1)\text{O}_4]$ ;  $[\text{H}_2\text{As}(2)\text{O}_4]^-$  and  $[\text{H}_3\text{As}(3)\text{O}_4]$ , respectively. The calculated average values of the distortion

indices [23] corresponding to the different distances and angles in  $[\text{AsO}_4]$  tetrahedral  $\text{DI}(\text{As}(1)\text{O}) = 0.0290$ ,  $\text{DI}(\text{As}(2)\text{O}) = 0.0384$ ,  $\text{DI}(\text{As}(3)\text{O}) = 0.0162$ ,  $\text{DI}(\text{OAs}(1)\text{O}) = 0.0197$ ,  $\text{DI}(\text{OAs}(2)\text{O}) = 0.0245$ ,  $\text{DI}(\text{OAs}(3)\text{O}) = 0.0326$ ,  $\text{DI}(\text{OO}) = 0.0167$ ,  $\text{DI}(\text{OO}) = 0.0123$  and  $\text{DI}(\text{OO}) = 0.0155$  show a high distortion of the (OO) distances of  $[\text{H}_3\text{As}(1)\text{O}_4]$ ;  $[\text{H}_2\text{As}(2)\text{O}_4]^-$  and  $[\text{H}_3\text{As}(3)\text{O}_4]$ , respectively.

Table 1. Crystal data and summary of intensity data collection and structure refinement of TEAs.

Parameter	TEAs
Formula	$\text{C}_8\text{H}_{28}\text{NAs}_3\text{O}_{12}$
Temperature (K)	293.0(2)
Wavelength MoK $\alpha$ ( $\text{\AA}$ )	0.71073
Crystal system	Monoclinic
Space group	Cc
Unit cell dimensions	
$a$ ( $\text{\AA}$ )	20.105(5)
$b$ ( $\text{\AA}$ )	7.842(2)
$c$ ( $\text{\AA}$ )	15.292(2)
$\beta$ ( $^\circ$ )	115.00(2)
$Z$	4
Calculated density, ( $\text{g}/\text{cm}^3$ )	1.53
$F(000)$	999.8
Crystal size (mm)	0.40 $\times$ 0.20 $\times$ 0.10
$\theta$ range for data collection ( $^\circ$ )	2.8-27.1
Index ranges	$-25 \leq h \leq 25$ $-9 \leq k \leq 1$ $-19 \leq l \leq 19$
$R_{\text{int}}$	0.0290
$R_{\text{(\sigma)}}(\text{sigma})$	0.0395
$R = \sum   F_o  -  F_c   / \sum   F_o  $	0.071
$R_w$	0.2200
$T_{\text{min}}$	0.2604
$T_{\text{max}}$	0.5745

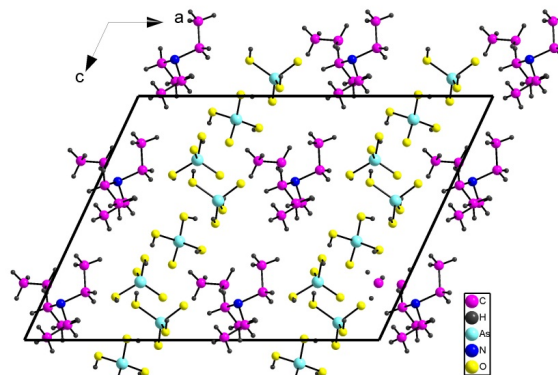


Figure 2. Projection along the  $b$  axis of the atomic arrangement of  $[(\text{CH}_3\text{CH}_2)_4\text{N}].[(\text{H}_2\text{AsO}_4)].[\text{H}_3\text{AsO}_4]_2$ .

The structure is based on sheets of  $\text{H}_2\text{AsO}_4^-$  and  $\text{H}_3\text{AsO}_4$  tetrahedra bonded together by strong intra-layer O-H...O hydrogen bonds, giving to trimmers built up by  $[(\text{H}_3\text{AsO}_4) (\text{H}_2\text{AsO}_4)]^-$  clusters, ( $d_{\text{O-O}} < 2.73 \text{ \AA}$ ) [24,25] as seen in Figure 3. The mid-planes of these arsenic groups, are located at  $x = 0.25$  and  $x = 0.75$ .

These hydrogen bonds contribute to the cohesion of the structure. The various hydrogen bond parameters are summarized in Table 3.

The organic cation are located at  $x = 0.0$  and  $x = 0.5$ . The lengths of the N-C bonds are in the range between 1.462(17) to 1.600(2)  $\text{\AA}$ . The C-N-C angles range from 101.6(10) to 115.9(12) $^\circ$ . The C-C bonds lengths are in the region between 1.477(13) to 1.611(14)  $\text{\AA}$ . They are in good agreement with those found in related compound [19,21].

### 3.3. Vibrational analysis

The FT-IR and FT-Raman spectra of the title crystals were measured for the powder sample at room temperature.

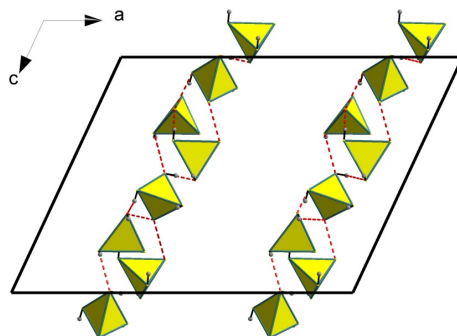
**Table 2.** Principal interatomic distances (Å) and angles (°) in TEAs.

Tetrahedron around As		[CH <sub>2</sub> CH <sub>2</sub> ] <sub>4</sub> N <sup>+</sup> cations	
As(1)-O(1)	1.671(12)	N-C(1)	1.60(2)
As(1)-O(2)	1.622(13)	N-C(2)	1.571(14)
As(1)-O(3)	1.663(14)	N-C(3)	1.470(14)
As(1)-O(4)	1.796(7)	N-C(4)	1.462(17)
O(1)-H(11)	0.8200	C(1)-C(7)	1.580(15)
O(4)-H(14)	0.8200	C(2)-C(8)	1.611(14)
O(3)-H(13)	0.8200	C(3)-C(5)	1.556(13)
As(2)-O(5)	1.731(9)	C(4)-C(6)	1.4777(3)
As(2)-O(6)	1.739(10)	C(1)-N-C(4)	114.2(12)
As(2)-O(7)	1.657(9)	C(1)-N-C(2)	104.9(11)
As(2)-O(8)	1.556(14)	C(4)-N-C(2)	101.6(10)
O(5)-H(22)	0.8200	C(1)-N-C(3)	108.8(12)
O(6)-H(23)	0.8200	C(4)-N-C(3)	115.9(12)
As(3)-O(9)	1.634(10)	C(2)-N-C(3)	110.7(12)
As(3)-O(10)	1.718(8)	C(8)-C(2)-N	114.1(12)
As(3)-O(11)	1.704(7)	C(6)-C(4)-N	112.7(6)
As(3)-O(12)	1.698(11)	C(5)-C(3)-N	108.7(10)
O(10)-H(33)	0.8200	C(1)-C(7)-N	98.1(9)
O(11)-H(34)	0.8200		
O(12)-H(31)	0.8200		
O(2)-As(1)-O(4)	107.7(5)		
O(2)-As(1)-O(1)	107.7(5)		
O(4)-As(1)-O(1)	113.5(6)		
O(4)-As(1)-O(3)	108.6(5)		
O(1)-As(1)-O(3)	109.4(6)		
O(2)-As(1)-O(3)	113.0(6)		
O(6)-As(2)-O(5)	107.6(6)		
O(6)-As(2)-O(7)	109.7(5)		
O(5)-As(2)-O(7)	110.6(5)		
O(6)-As(2)-O(8)	103.1(6)		
O(5)-As(2)-O(8)	110.5(6)		
O(7)-As(2)-O(8)	114.8(6)		
O(11)-As(3)-O(10)	108.6(4)		
O(11)-As(3)-O(9)	106.2(5)		
O(10)-As(3)-O(9)	109.2(5)		
O(11)-As(3)-O(12)	115.8(5)		
O(10)-As(3)-O(12)	103.0(5)		
O(9)-As(3)-O(12)	113.8(3)		

**Table 3.** Bond lengths (Å) and bond angles (°) in the hydrogen bonding scheme of [(CH<sub>2</sub>CH<sub>2</sub>)<sub>4</sub>N][H<sub>2</sub>AsO<sub>4</sub>].[H<sub>2</sub>AsO<sub>4</sub>]<sub>2</sub>.

D-H...A	d(D-H) (Å)	d(H...A) (Å)	d(D...A) (Å)	∠D-H...A (°)
O(3)-H(13)...O(12) <sup>i</sup>	0.82	2.04	2.669(15)	132.7
O(4)-H(14)...O(7)	0.82	1.80	2.614(13)	169.4
O(5)-H(22)...O(12) <sup>iv</sup>	0.82	2.25	2.560(13)	102.5
O(6)-H(23)...O(9) <sup>ii</sup>	0.82	1.86	2.453(16)	128.7
O(10)-H(33)...O(7)	0.82	1.82	2.581(13)	154.3
O(12)-H(31)...O(3) <sup>iii</sup>	0.82	1.87	2.669(15)	165.3

Symmetry codes: (i)  $x, -y+1, z+1/2$ ; (ii)  $x, y-1, z$ ; (iii)  $x, -y+1, z-1/2$ ; (iv)  $x, -y, z+1/2$ .

**Figure 3.** Projection along the *b* axis of the inorganic arrangement of TEAs.

The bands observed in the measured region arise from the vibrations of hydrogen bonds, vibrations of the tetraethyl ammonium cation, arsenic groups and lattice vibrations. Vibrational spectra are shown in Figure 4-5.

The vibrational analysis of an isolated arsenate, phosphate anion  $\text{AsO}_4^{3-}$ , with  $T_d$  point group symmetry leads to four Raman active normal modes:  $\nu_1(A_1)$ ,  $\nu_2(E)$ ,  $\nu_3(F_2)$  and  $\nu_3(F_2)$  with average wavenumbers 837, 349, 887 and 463  $\text{cm}^{-1}$ ,

respectively [26].  $\nu_1$  and  $\nu_3$  involve the symmetric and the anti-symmetric stretching mode of the As-O bonds, whereas  $\nu_2$  involve mainly O-As-O, symmetric and anti-symmetric bending modes. The IR and Raman spectra of TEAs, that we obtained consist of a number of distinct and well separated groups of bands, and can be divided into three frequency regions: 15-250  $\text{cm}^{-1}$ , lattice mode; 250-1200  $\text{cm}^{-1}$ ,  $\text{AsO}_4^{3-}$ , internal modes and 1200-3700  $\text{cm}^{-1}$ , high-frequency hydrogen modes [27-29]. In

TEAs crystal, the symmetry of  $\text{AsO}_4^{3-}$  ions is reduced from  $T_d$  to  $C_1$ . In fact, our structural study on TEAs shows that the As-O, distances and the O-As-O, angles are distorted with respect to the hypothetical  $T_d$  symmetry. This symmetry change partially removes the degeneracy of the vibrational wave functions, which would have characterized free  $\text{AsO}_4^{3-}$ . In the 1000-300  $\text{cm}^{-1}$  region, the  $\text{AsO}_4^{3-}$  stretching and bending vibrations expected to appear, as well as the modes associated to internal modes of the organic cations. However, in the light of our present calculations as primary source of assignment and by comparison with similar organic arsenic compound, we have been distinguishing between the bands originating from the vibrations of arsenate groups and the organic cations. The medium band at 907  $\text{cm}^{-1}$  in Raman spectrum is assigned to the asymmetric stretching  $\nu_3$  mode of the arsenate ion. In IR spectrum, this mode appears also as a single strong band at 920  $\text{cm}^{-1}$ . The band due to the symmetric stretching mode  $\nu_1$  vibration is located in Raman spectrum at 829 and 671  $\text{cm}^{-1}$  as a strong band. In IR spectrum this mode appears as a strong band at 822 and 677  $\text{cm}^{-1}$ . The bands due to the symmetric and asymmetric bending vibration  $\nu_2$  and  $\nu_4$  of the arsenate ion are identified in the 550-400  $\text{cm}^{-1}$  and 400-300  $\text{cm}^{-1}$  frequency region, respectively. The very strong band observed in Raman spectrum at 417  $\text{cm}^{-1}$  can be easily assigned to  $\nu_4$  mode, whereas the symmetric mode  $\nu_2$  appears in Raman spectrum as weak band at 324  $\text{cm}^{-1}$ .

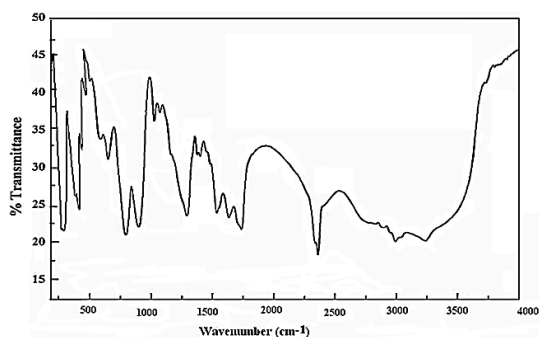


Figure 4. IR spectrum of  $[(\text{CH}_3\text{CH}_2)_4\text{N}(\text{H}_2\text{AsO}_4)(\text{H}_3\text{AsO}_4)_2]$ .

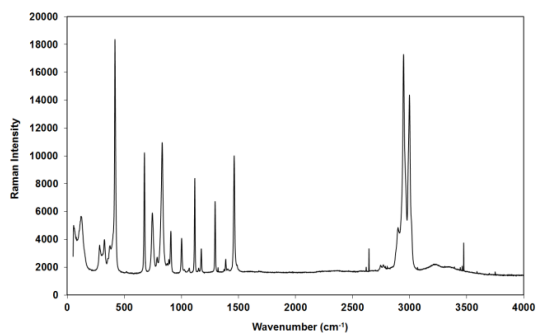


Figure 5. Raman spectrum of  $[(\text{CH}_3\text{CH}_2)_4\text{N}(\text{H}_2\text{AsO}_4)(\text{H}_3\text{AsO}_4)_2]$ .

Numerous functional and skeletal groups such as  $\text{CH}_2$ ,  $\text{CH}_3$ , C-N, C-C and  $\text{NC}_4$  are present in tetrapropylammonium cation. These groups are manifested in IR and Raman spectra in different range with different intensity.

It is well known that  $\text{CH}_3$  groups have  $C_{3v}$  symmetry in the free state with pyramidal structure of TEAs. Their normal modes of vibrations are  $\nu_1(A_1)$ ,  $\nu_2(A_1)$ ,  $\nu_3(E)$  and  $\nu_4(E)$ . All these modes are both infrared and Raman active with the asymmetric stretching and bending modes being doubly degenerate. The asymmetric and symmetric  $\text{CH}_3$  stretching vibrations in aliphatic compound are usually observed in the region 2990-

2850  $\text{cm}^{-1}$  [30-31]. In the title compound the doubly degenerate asymmetric stretching and bending modes  $\nu_3(E)$  and  $\nu_4(E)$  are observed in the split form. The weak band at 2944  $\text{cm}^{-1}$  and the shoulder one at 2948  $\text{cm}^{-1}$  in IR spectrum are attributed to the asymmetric stretching vibration and the Raman counterparts are located as a very strong band at 2997  $\text{cm}^{-1}$ . The symmetric stretching mode of  $\text{CH}_3$  is assigned to the shoulder band at 2897  $\text{cm}^{-1}$  in Raman spectrum. In IR spectrum this mode appears as a very weak intensity band at the 2848  $\text{cm}^{-1}$ . The asymmetric and symmetric bending mode of methyl group generally appears in the region 1550-1410 and 1310-1400  $\text{cm}^{-1}$ , [32-33]. In the present case, two FT-IR bands with slightly different intensity at 1447 and 1478  $\text{cm}^{-1}$  are assigned to  $\text{CH}_3$  asymmetric bending mode. In Raman spectrum, their corresponding bands appear as a very shoulder band at 1452  $\text{cm}^{-1}$  and as a very strong one at 1462  $\text{cm}^{-1}$ . The symmetric bending mode of the  $\text{CH}_3$  group is seen at 1392  $\text{cm}^{-1}$  as a medium band in the IR spectrum and as a very strong band at 1385  $\text{cm}^{-1}$  in Raman spectrum. The methyl rocking vibration is observed as a weak band at 997  $\text{cm}^{-1}$  in IR spectrum and at 1001  $\text{cm}^{-1}$  as a medium one in Raman spectrum.

The wavenumber of the  $\text{CH}_2$  vibrational modes depend on its immediate environment. The stretching modes of the  $\text{CH}_2$  group usually occur in the region 3100-2800  $\text{cm}^{-1}$  [34-35]. In TEAs crystal, the  $\text{CH}_2$  asymmetric and symmetric stretching modes are not identified in IR spectrum. These bands are probably masked by the broad bands of  $\text{CH}_3$  stretching vibrations. The weak band located at 2874  $\text{cm}^{-1}$  in Raman spectrum is assigned to the  $\text{CH}_2$  symmetric stretching mode. The deformation modes of this group lie in the same region as the deformation modes of  $\text{CH}_3$ . Since the deformation modes of methyl group are intense, the deformation modes of  $\text{CH}_2$  are also not identified. However the wagging, twisting and the rocking modes of the  $\text{CH}_2$  group were observed and assigned.

The primitive unit cell of the title compound contains one tetraethylammonium ( $\text{NC}_4$ )<sup>+</sup> cation not coupled with the inorganic parts as revealed by the X-Ray diffraction. Then, it is convenient as a first approach to consider the  $\text{NC}_4$  core of the isolated cation with  $T_d$  symmetry and therefore exhibits four normal modes. According to the literature, the vibrations related to  $\text{NC}_4$  group shown in tetraethylammonium cation of TEAs are described as: symmetric stretching mode  $\nu_1(A)$  to be found at 752  $\text{cm}^{-1}$ , [36-38] asymmetric stretching mode  $\nu_3(F_2)$  located at 955  $\text{cm}^{-1}$ , asymmetric bending mode  $\nu_4(F_2)$  observed at 455  $\text{cm}^{-1}$  and the symmetric bending mode  $\nu_2(F_2)$  at 372  $\text{cm}^{-1}$  [32,39]. In our case the weak band appeared at 1001, 1000  $\text{cm}^{-1}$  is related to the  $\nu_3$  mode. His counterpart appears in IR spectrum as shoulder band at 988  $\text{cm}^{-1}$ . The weak band observed in Raman spectrum at 744  $\text{cm}^{-1}$  arises from the  $\nu_1$  symmetric stretching mode. The bands assigned to the symmetric and asymmetric bending modes of  $\text{NC}_4$  core of the isolated cation are observed in Raman spectrum at 383  $\text{cm}^{-1}$  respectively whereas the corresponding calculated values for these modes are located at 393  $\text{cm}^{-1}$ , respectively. It is interest to note that the vibrational mode of the  $\text{NC}_4$  group do not deviate much from their expected values, suggesting that the interaction of this group with the environment is not strong on the other hand, we note also that our assignment of  $\text{NC}_4$  agree well with the previous reported vibrational studies of the tetraethylammonium salts [40].

It is well known that hydrogen bonding brings a remarkable downward wavenumber shifts. The intermolecular hydrogen bonds give rise to broad bands, whereas bands arising from intramolecular hydrogen bonds are sharp and well resolved. Other information which can be obtained from the vibrational spectra concerns the strength and the type of O-H...O hydrogen bonds, which remain practically the same in the strongly hydrogen bonded crystals such as  $\text{KH}_2\text{PO}_4$ ,  $\text{NaH}_2\text{PO}_4$ ,  $\text{CsHSO}_4$ , and  $\text{CsH}_2\text{PO}_4$  [41-44]. The corresponding OH stretching vibration gives rise to characteristic broad trio bands of ABC type, associated with strongly hydrogen-bonded systems.

These bonds have been interpreted as OH stretching modes in Fermi resonance with combinations involving mainly OH bending vibrations or in terms of a strong coupling between fast OH and O...O stretching modes [45,46]. By knowing the bond length, the strength of the hydrogen bond can be determined as very strong (below 2.5 Å), strong (2.5-2.7 Å), normal (2.7-2.9 Å) and weak (above 2.9 Å). X-ray diffraction analysis of TEAs, reveal that the structure is based on sheets of  $\text{H}_2\text{AsO}_4^-$ ,  $\text{H}_3\text{AsO}_4$  tetrahedra bonded together by strong intra-layer O-H...O hydrogen bonds, giving to trimmers. The inspection of the IR spectrum reveals a broad and strong band at  $3660\text{ cm}^{-1}$ . We have assigned this band to the stretching mode  $\nu(\text{OH})$  which is not implied in hydrogen bonding. Two broad and weak bands in IR spectrum located at  $3526$  and  $3440\text{ cm}^{-1}$  are assigned to  $\nu(\text{O-H}\cdots\text{O})$  modes. In Raman spectrum, a broad and weak band at  $3244\text{ cm}^{-1}$  is also assigned to  $\nu(\text{O-H}\cdots\text{O})$  stretching modes. The in-plane OH bending mode  $\delta\text{OH}$  gives rise to a medium band in infrared spectrum with a counterpart in Raman spectrum at  $1244\text{ cm}^{-1}$ . The out-of-plane bending  $\gamma\text{OH}$  mode appears in the region  $900\text{-}700\text{ cm}^{-1}$ .

### 3.4. Calorimetric study

DSC-TG of TEAs was done in air at the rate of  $5\text{ }^\circ\text{C}/\text{min}$ . One more characteristic feature of the room temperature TEAs is its high hygroscopicity (Figure 6-7) which, illustrates the calorimetric (DSC) and thermogravimetric (TGA) results. This compound is stable until 345 K, above this temperature; a loss of weight appears at 369 K of TEAs. It is due to the departure of adsorbed water. The two endothermic peak observed at  $T = 388\text{ K}$  is attributed to the melting of TEAs.

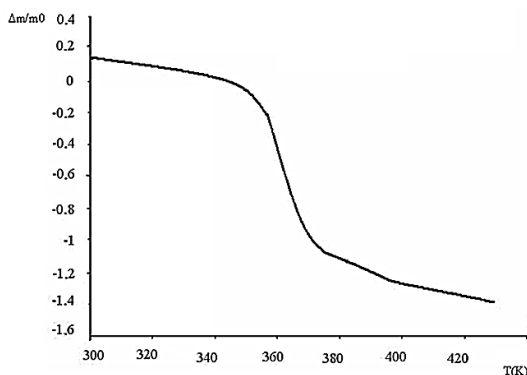


Figure 6. The TG curve of  $[(\text{CH}_3\text{CH}_2)_4\text{N}](\text{H}_2\text{AsO}_4)(\text{H}_3\text{AsO}_4)_2$ .

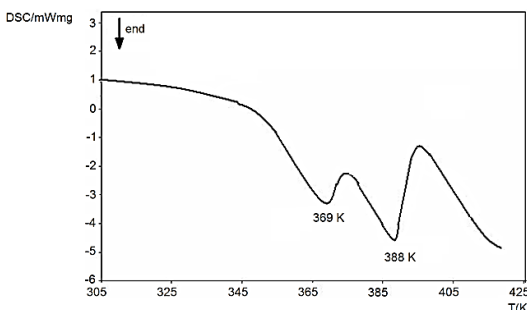


Figure 7. The DSC curve of  $[(\text{CH}_3\text{CH}_2)_4\text{N}](\text{H}_2\text{AsO}_4)(\text{H}_3\text{AsO}_4)_2$ .

### 4. Conclusion

The new hybrid material,  $[(\text{CH}_3\text{CH}_2)_4\text{N}][\text{H}_2\text{AsO}_4][\text{H}_3\text{AsO}_4]_2$ , has been synthesized and investigated by thermal analysis, single crystal X-ray diffraction and vibrational spectroscopy.

The structure consist of strong two dimensional character based on sheets of  $\text{H}_2\text{AsO}_4^-$  and  $\text{H}_3\text{AsO}_4$  tetrahedra fused together by strong intra-layer O-H...O hydrogen bonds, giving to trimmers and infinite chains. Vibrational study recorded is of great interest as it verifies the dependence of groups constituting our material. The hydrogen bonds confirmed by IR and X-Ray diffraction explain the stability of our compound. DSC anomalies definitively indicate on adsorbed water and on melting.

### Acknowledgement

Grateful thanks are expressed in Dr. Philippe Guionneau (Service Rayons X /ICMCB CNRS Bordeaux) for the assistance in single crystal X-ray diffraction data collection.

### Supplementary material

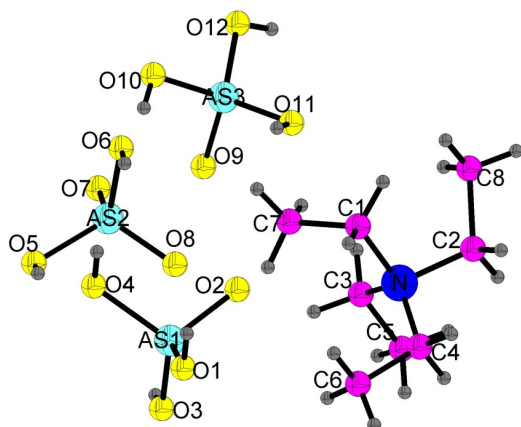
CCDC-927292 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge via [www.ccdc.cam.ac.uk/data\\_request/cif](http://www.ccdc.cam.ac.uk/data_request/cif), or by e-mailing [data\\_request@ccdc.cam.ac.uk](mailto:data_request@ccdc.cam.ac.uk), or by contacting The Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK; fax: +44(0)1223-336033.

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## GRAPHICAL ABSTRACT



It is very important to confirm the author(s) last, middle and first names in order to be displayed correctly on our website as well as in the indexing databases.

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