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## SOME NEW SULFATO AND HYDROGENOSULFATO ADDUCTS: SYNTHESIS, INFRARED AND MÖSSBAUER STUDIES

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**Abstract:** Eight organotin (IV) (mainly sulfato) adducts have been synthesized and studied by spectroscopic methods. While considering the anionic component, the suggested structures are discrete; supramolecular architectures are obtained with secondary interactions through NH---Cl and NH---O hydrogen bonds while considering the cations, the anions behaving as monochelating, bridging or monocoordinating ligands, the environment around the tin (IV) centre being octahedral. Tetrahedral SnMe<sub>2</sub>Cl<sub>2</sub> has been characterized spectroscopically.

**Keywords:** organotin (IV) adducts, infrared, Mossbauer, ionic structures, hydrogen bonds, supramolecular architectures, tetrahedral SnMe<sub>2</sub>Cl<sub>2</sub>.

## INTRODUCTION

The various applications of organotin (IV) compounds in many fields: agriculture, medicine, antifouling paints, wood preservatives, ... [1 – 3], are mainly the reasons for many research groups to be involved in the synthesis of compounds of this family. Structures of some sulfato derivatives:  $(\text{SnMe}_3)_2\text{SO}_4 \cdot 2\text{H}_2\text{O}$  and  $(\text{SnPh}_3)_2\text{SO}_4 \cdot \text{H}_2\text{O}$ , and adducts:  $\text{Bu}_4\text{NHSO}_4 \cdot \text{SnMe}_3\text{Cl}$ , have been reported by Molloy *et al.* [4] and us [5, 6]. Our group has yet reported many papers dealing with the coordinating behavior of oxoanions [7 – 9]. We have initiated here, the study of the interactions between:

- $\text{Bu}_4\text{NHSO}_4$  and  $\text{SnBu}_2\text{Cl}_2$
- $\text{Cy}_2\text{NH}_2\text{HSO}_4$  and  $\text{SnR}_2\text{Cl}_2$  (R = Me, Bu),  $\text{SnMe}_3\text{Cl}$
- $\text{NH}_2\text{SO}_3\text{H}$ ,  $\text{Et}_2\text{NH}$  and  $\text{SnMe}_2\text{Cl}_2$ ,
- $\text{isoBu}_2\text{NH}$ ,  $\text{H}_2\text{SO}_4$  and  $\text{SnMe}_2\text{Cl}_2$

which have yielded eight new  $\text{SnR}_2$  and  $\text{SnMe}_3$  residues containing adducts. Infrared and Mössbauer studies of these adducts have been carried out and structures were suggested on the basis of spectroscopic data.

## EXPERIMENTAL

When  $\text{Bu}_4\text{NHSO}_4$  in ethanol or  $\text{Cy}_2\text{NH}_2\text{HSO}_4$  in methanol is mixed with  $\text{SnBu}_2\text{Cl}_2$  in ethanol in 2 : 1 ratio (**A**), in ether in 1 : 1 ratio (**B**) or  $\text{SnMe}_2\text{Cl}_2$  in ether in 1 : 1 (**C**) or 1 : 2 (**D**), white powders are obtained after a slow solvent evaporation.

Mixing  $\text{H}_2\text{NSO}_3\text{H}$  in water,  $\text{Et}_2\text{NH}$  in water with  $\text{SnMe}_2\text{Cl}_2$  in ethanol in 1 : 1 : 2 ratio gives a white powder after a slow solvent evaporation (**E**).

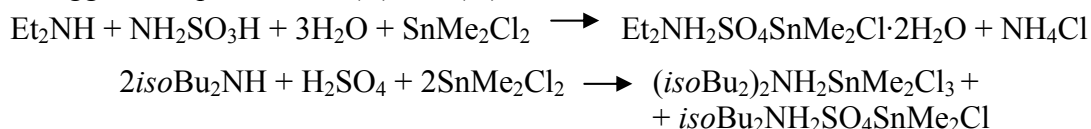
On mixing  $(\text{Cy}_2\text{NH}_2)_2\text{SO}_4 \cdot 2\text{H}_2\text{O}$  (obtained on mixing in water  $\text{H}_2\text{SO}_4$  and  $\text{Cy}_2\text{NH}$  in 1 : 2 ratio and allowing water evaporation) in MeOH with  $\text{SnBu}_2\text{Cl}_2$  in MeOH in 1 : 2 ratio, a white powder is obtained after a slow solvent evaporation (**F**).

Mixing  $\text{Cy}_2\text{NH}_2\text{HSO}_4 \cdot 2\text{H}_2\text{O}$  (obtained on mixing in water  $\text{H}_2\text{SO}_4$  and  $\text{Cy}_2\text{NH}$  in 1 : 1 ratio and allowing water evaporation) in MeOH with  $\text{SnMe}_3\text{Cl}$  in MeOH in 1 : 1 ratio, a white powder is obtained after a slow solvent evaporation (**G**).

The mixture of  $\text{isoBu}_2\text{NH}$  in water,  $\text{H}_2\text{SO}_4$  in water with  $\text{SnMe}_2\text{Cl}_2$  in ethanol in 1 : 1 : 1 ratio gives a white powder after a slow solvent evaporation (**H**).

The analytical data reported below allows suggesting the following formulae, presented in Table 1.

The suggested equations for (**E**) and (**H**) are:



In the first reaction, the hydrolysis of  $\text{NH}_2\text{SO}_3\text{H}$  in basic media has led to the sulphate.

$\text{isoBu}_2\text{NH}_2\text{SO}_4\text{SnMe}_2\text{Cl}$ , the homologue of  $\text{Et}_2\text{NH}_2\text{SO}_4\text{SnMe}_2\text{Cl} \cdot 2\text{H}_2\text{O}$  in the second reaction has not been isolated but  $(\text{isoBu}_2)_2\text{NH}_2\text{SnMe}_2\text{Cl}_3$ .

**Table 1.** Formulae of synthesized adducts, based on the elemental analyses

Adduct	Chemical formula	Elemental analysis (%)									
		C		H		N		Sn		Cl	
		a*	b**	a*	b**	a*	b**	a*	b**	a*	b**
<b>A</b>	$\text{Bu}_4\text{NHSO}_4 \cdot \text{SnBu}_2\text{Cl}_2$	44.80	44.95	8.55	8.65	2.18	2.26	18.46	18.26	11.04	11.22
<b>B</b>	$\text{Cy}_2\text{NH}_2\text{HSO}_4 \cdot \text{SnBu}_2\text{Cl}_2$	41.15	41.32	7.37	7.50	2.40	2.32	20.35	20.40	12.17	12.31
<b>C</b>	$\text{Cy}_2\text{NH}_2\text{HSO}_4 \cdot \text{SnMe}_2\text{Cl}_2$	33.66	33.44	6.21	6.33	2.81	2.77	23.78	23.87	14.23	14.43
<b>D</b>	$3\text{Cy}_2\text{NH}_2\text{HSO}_4 \cdot 2\text{SnMe}_2\text{Cl}_2$	37.57	37.42	6.81	6.64	3.29	3.15	18.58	19.00	11.12	11.34
<b>E</b>	$\text{Et}_2\text{NH}_2\text{SO}_4\text{SnMe}_2\text{C} \cdot 2\text{H}_2\text{O}$	18.45	18.22	5.64	5.54	3.59	3.73				
<b>F</b>	$(\text{Cy}_2\text{NH}_2)_2\text{SO}_4 \cdot \text{SnBu}_2\text{Cl}_2 \cdot 2\text{H}_2\text{O}$	48.02	48.26	8.75	8.64	3.50	3.45				
<b>G</b>	$\text{Cy}_2\text{NH}_2\text{HSO}_4 \cdot \text{SnMe}_3\text{Cl}$	37.56	37.46	7.09	6.93	2.92	3.07				
<b>H</b>	$(\text{isoBu})_2\text{NH}_2\text{SnMe}_2\text{Cl}_3$	29.05	29.24	7.15	7.04	3.46	3.39				

\* - calculated;

\*\* - found.

The elemental analyses have been performed by the CNRS “Service Central d’Analyses” Vernaison-France or the Centre of Microanalyses, University of Bath, UK. The IR spectra were recorded at the University of Cheikh Anta Diop (Dakar, Sénégal) and at the University College of Saint-Boniface (Winnipeg, Canada) by means of a Bruker FT-IR spectrometer, at the University of Padova (Italy) using a PE 580 or a Bruker FTIR spectrometer, the sample being as Nujol mulls, the windows being CsI or polyethylene. Mössbauer spectra were obtained as described previously [9, 10]. Infrared data are given in  $\text{cm}^{-1}$  [abbreviations: (vs) very strong, (s) strong, (m) medium, (w) weak, (sh) shoulder]. Mössbauer parameters are given in  $\text{mm} \cdot \text{s}^{-1}$  (abbreviations: Q.S = quadrupole splitting, I.S = isomer shift,  $\Gamma$  = full width at half-height, A = Area). All the chemicals are from Aldrich Company and were used without any further purification.

## RESULTS AND DISCUSSION

Let us consider the more relevant IR bands of the studied compounds:

**(A):**  $\nu \text{SnC}_2 = 691\text{m}$ ;  $\nu \text{SnC}_2 = 625 \text{w}$ ;  $\nu \text{SO}_4 = (1060 \text{vs}, 1150 \text{sh}, 1224 \text{vs})$ ;  $\delta \text{SO}_4 = 589 \text{s}$ ;  $\nu \text{SnCl} = 254 \text{m}$ ;

**(B):**  $\nu \text{SnC}_2 = 557 \text{w}$ ;  $\nu \text{SO}_4 = (979 \text{m}, 1080 \text{s}, 1111 \text{vs})$ ;  $\delta \text{SO}_4 = (427 \text{vs}, 592 \text{m}, 619 \text{m})$ ;  $\nu \text{SnCl} = 302 \text{s}$ ;  $\nu \text{SnO} = 212 \text{w}$ ;  $\nu \text{NH}_2 = 3434 \text{s}$ ;  $\delta \text{NH}_2 = 1646 \text{s}$ ;

**(C):**  $\nu \text{SnC}_2 = 549 \text{m}$ ;  $\nu \text{SnCl} = 253 \text{m}$ ;  $\nu \text{SnO} = 202 \text{s}$ ;  $\nu \text{SO}_4 = (964 \text{w}, 1095 \text{s}, 1184 \text{vs})$ ;  $\delta \text{SO}_4 = (445 \text{w}, 592 \text{vs})$ ;  $\nu \text{NH}_2 = 3434 \text{s}$ ;  $\delta \text{NH}_2 = 1646 \text{s}$ ;

**(D):**  $\nu \text{SnC}_2 = 520 \text{w}$ ;  $\nu \text{SnC}_2 = 547 \text{m}$ ;  $\nu \text{SO}_4 = (964 \text{m}, 1057 \text{sh}, 1095 \text{s}, 1140 \text{sh})$ ;  $\delta \text{SO}_4 = (445 \text{w}, 592 \text{m})$ ;  $\nu \text{SnCl} = 254 \text{vs}$ ;  $\nu \text{SnO} = 202 \text{w}$ ;  $\nu \text{NH}_2 = 3434 \text{s}$ ;  $\delta \text{NH}_2 = 1646 \text{s}$ ;

**(E):**  $\nu \text{SnC}_2 = 519 \text{m}$ ;  $\nu \text{SnCl} = 353 \text{m}$ ;  $\nu \text{SnO} = 212 \text{s}$ ;  $\nu \text{SO}_4 = (1050 \text{vs}, 1195 \text{vs})$ ;  $\delta \text{SO}_4 = (427 \text{vs}, 584 \text{vs})$ ;  $\nu \text{NH}_2 = 3434 \text{s}$ ;  $\delta \text{NH}_2 = 1646 \text{s}$ ;

**(F):**  $\nu$   $\text{SnC}_2 = 546$  s;  $\nu$   $\text{SnC}_2 = 520$  m;  $\nu$   $\text{SnCl} = 254$  vs;  $\nu$   $\text{SnO} = 202$  w;  $\nu$   $\text{NH}_2 = (3100$  s, 3530 s);  $\delta$   $\text{NH}_2 = (1594$  s, 1610 s);

**(G):**  $\nu$   $\text{SnC}_2 = 622$  s;  $\nu$   $\text{SnC}_2 = 595$  m;  $\nu$   $\text{SO}_4 = (1040$  s, 1174 s);  $\nu$   $\text{NH}_2 = 3430$  s;  $\delta$   $\text{NH}_2 = 1566$  m;

**(H):**  $\nu$   $\text{SnC}_2 = 557$  m;  $\nu$   $\text{SO}_4 = (871$  vs, 1035 vs, 1120 vs);  $\delta$   $\text{SO}_4 = (452$  m, 480 m, 580 m, 616);  $\nu$   $\text{NH}_2 = (2856$  vs, 2937 vs, 3047 vs);  $\delta$   $\text{NH}_2 = 1594$  s;

and their Mossbauer data:

**(A):** IS = 1.68, QS = 4.18,  $\Gamma = 1.00$ ;

**(B):** IS = 1.52, QS = 3.72,  $\Gamma = 1.02$ ;

**(C):** n/a

**(D):** IS = 1.58, QS = 4.85,  $\Gamma = 1.01$ ;

**(E):** IS<sub>1</sub> = 1.41, QS<sub>1</sub> = 2.83,  $\Gamma_1 = 0.97$ , A<sub>1</sub> = 50, IS<sub>2</sub> = 0.94, QS<sub>2</sub> = 2.24,  $\Gamma_2 = 0.87$ , A<sub>2</sub> = 50;

**(F):** IS = 1.05, QS = 2.01,  $\Gamma = 0.98$ ;

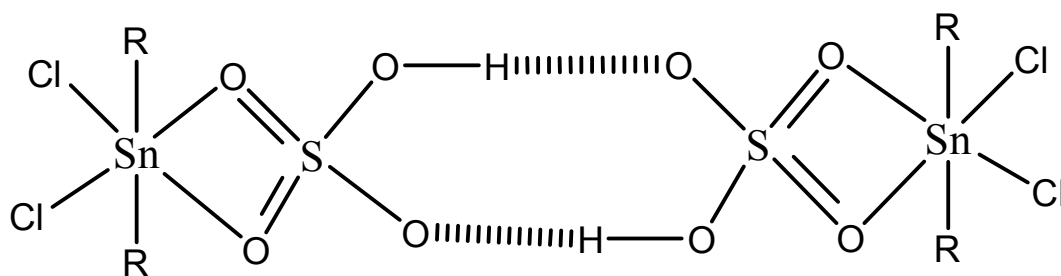
**(G):** QS = 3.67, IS<sub>1</sub> = 1.04,  $\Gamma = 0.98$ ;

**(H):** IS = 0.80, QS = 3.19,  $\Gamma = 0.90$ .

**Bu<sub>4</sub>NHSO<sub>4</sub>·SnBu<sub>2</sub>Cl<sub>2</sub> (A), Cy<sub>2</sub>NH<sub>2</sub>H<sub>2</sub>SO<sub>4</sub>·SnBu<sub>2</sub>Cl<sub>2</sub> (B), Cy<sub>2</sub>NH<sub>2</sub>H<sub>2</sub>SO<sub>4</sub>·SnMe<sub>2</sub>Cl<sub>2</sub> (C)**

The values of the quadrupole splitting of **(A)** and **(B)** (4.18 and 3.72 mm·s<sup>-1</sup>) are consistent with trans coordinated SnBu<sub>2</sub> residue according to Platt *et al.* [12, 13]. The absence of  $\nu$ SnMe<sub>2</sub> on the IR spectrum of **(C)** is an indication of the presence of a *trans* coordinated SnR<sub>2</sub> residue according to Group Theory [14].

The Mössbauer and infrared data allow to suggest while considering the complex-anion [HSO<sub>4</sub>·SnR<sub>2</sub>Cl<sub>2</sub>]<sup>-</sup> (R = Me, Bu), the structure reported on Figure 1, the hydrogenosulfate behaving as a monochelating ligand. The monomers are linked by OH----O hydrogen bonds leading to a dimeric structure.

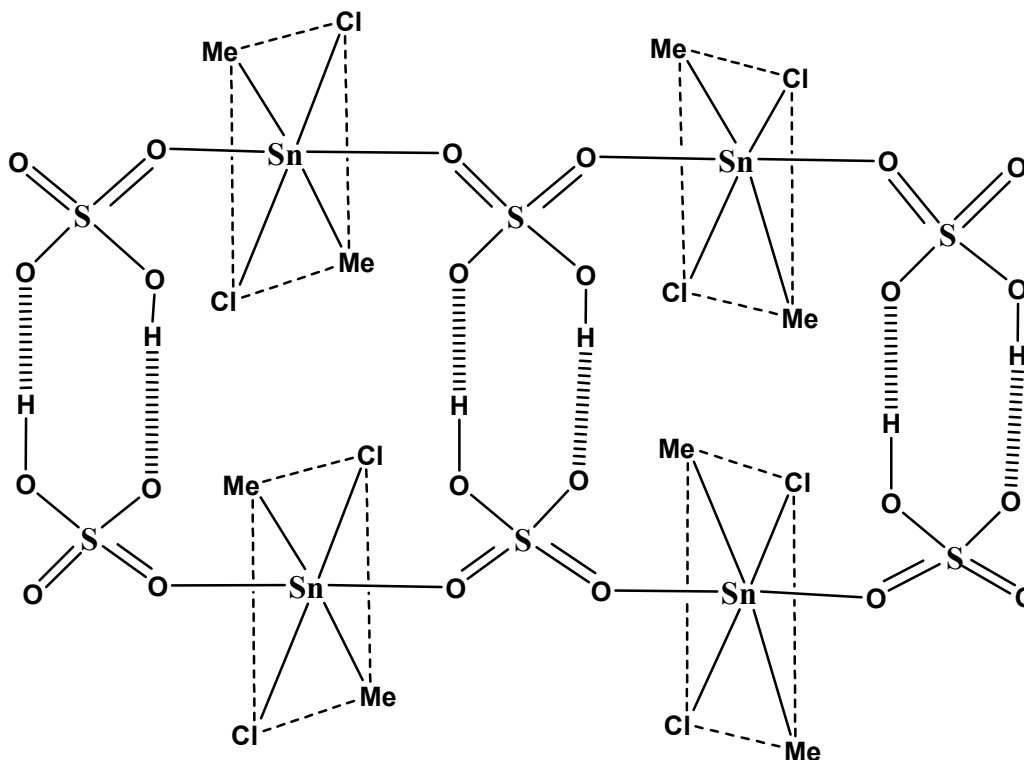


**Figure 1.** Dimeric structure of the complex-anion [HSO<sub>4</sub>·SnR<sub>2</sub>Cl<sub>2</sub>]<sup>-</sup> (R = Me, Bu)

In the case of **(B)** and **(C)** when the cations, involved through hydrogen bonds (NH----O or NH----Cl) are considered, supramolecular architecture are obtained.

**3C<sub>2</sub>NH<sub>2</sub>HSO<sub>4</sub>·2SnMe<sub>2</sub>Cl<sub>2</sub> (D)**

While considering the complex-anion  $[(H-OSO_3)_3(SnMe_2Cl_2)_2]^{3-}$ , the value of the quadrupole splitting ( $4.85 \text{ mm}\cdot\text{s}^{-1}$ ) indicates a SnMe<sub>2</sub> residue in a *trans* octahedral environment according to Platt *et al.* [12, 13] allowing to suggest the dimeric structure reported on Figure 2 (the very high value of the QS indicates planar SnMe<sub>2</sub>Cl<sub>2</sub> molecules belonging to D<sub>2h</sub> point group). When the cations are involved through NH----O or NH----Cl hydrogen bonds create supramolecular architectures.



**Figure 2.** Structure of the the complex-anion  $[(H-OSO_3)_3(SnMe_2Cl_2)_2]^{3-}$

**Et<sub>2</sub>NH<sub>2</sub>SO<sub>4</sub>SnMe<sub>2</sub>Cl·2H<sub>2</sub>O (E)**

The Mössbauer data show the presence of two types of tin centre in (E) consistent with the presence of the complex-anion  $[SnMe_2(SO_4)_2]^{2-}$  (in *cis* conformation (QS =  $2.24 \text{ mm}\cdot\text{s}^{-1}$ ) with monochelating sulfate anions, the tin centre being octahedral and tetrahedral lattice SnMe<sub>2</sub>Cl<sub>2</sub> molecules (QS =  $2.83 \text{ mm}\cdot\text{s}^{-1}$ ) according to Platt *et al.* [12, 13] – in SnPh<sub>2</sub>Cl<sub>2</sub>, QS =  $2.88 \text{ mm}\cdot\text{s}^{-1}$ . The complex anions are hold together by cations through hydrogen bonds giving a supramolecular structure, a piece of which is reported in Figure 3 (a structure containing lattice SnMe<sub>2</sub>Br<sub>2</sub> molecules has yet been reported from an X ray study) [15]). The anion  $[SnMe_2(SO_4)_2]^{2-}$  is structurally similar to  $[SnMe_2(C_2O_4)_2]^{2-}$  yet reported [16, 17]. To the best of our knowledge a tetrahedral SnMe<sub>2</sub>Cl<sub>2</sub> has never been characterized by Mössbauer spectroscopy. The water molecules can be lattice ones or involved in the hydrogen bonds network of the supramolecular architecture.

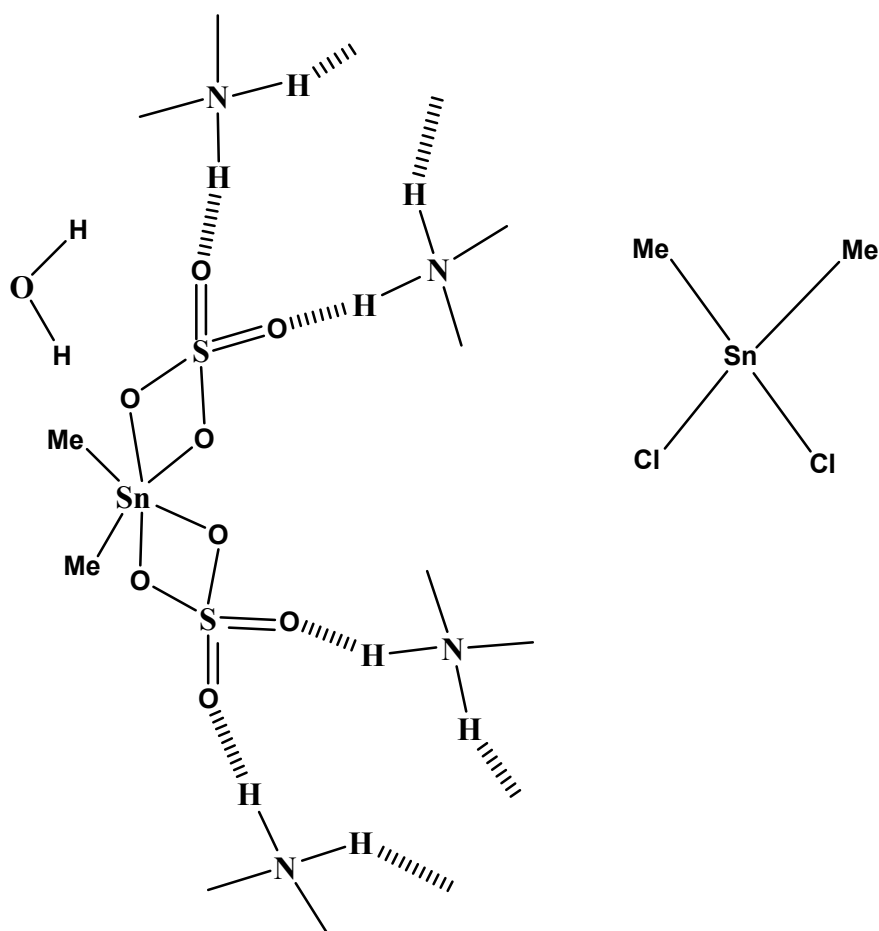


Figure 3. Supramolecular structure of adduct (E)

$(\text{Cy}_2\text{NH}_2)_2\text{SO}_4 \cdot \text{SnBu}_2\text{Cl}_2 \cdot 2\text{H}_2\text{O}$  (F)

The value of the quadrupole splitting ( $QS = 2.01$ ) is consistent with a  $\text{SnBu}_2$  residue *cis* octahedrally coordinated according to Platt *et al.* [12, 13] allowing to suggest while considering the complex-anion  $[\text{SO}_4 \cdot \text{SnBu}_2\text{Cl}_2]^{2-}$  the discrete structure reported on Figure 4). When the cations, through  $\text{NH} \cdots \text{O}$  or  $\text{NH} \cdots \text{Cl}$  hydrogen bonds are involved, supramolecular architecture are obtained (we report arbitrary the dimeric structure involving the cations in Figure 5).

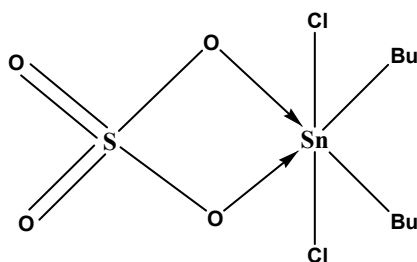


Figure 4. Structure of the complex-anion  $[\text{SO}_4 \cdot \text{SnBu}_2\text{Cl}_2]^{2-}$

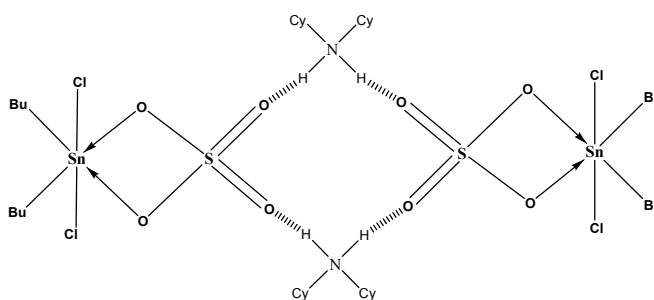
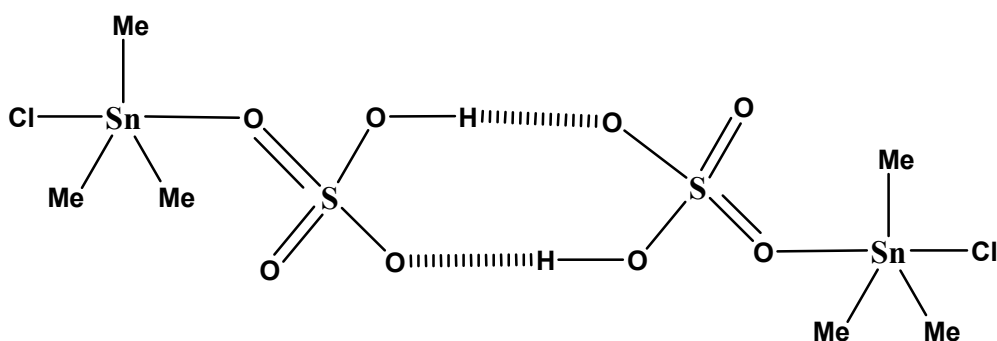


Figure 5. The supramolecular structure due to the  $\text{NH} \cdots \text{O}$  or  $\text{NH} \cdots \text{Cl}$  hydrogen bonds

**Cy<sub>2</sub>NH<sub>2</sub>HSO<sub>4</sub>·SnMe<sub>3</sub>Cl (G)**

In recent papers we have reported the X ray structure of Bu<sub>4</sub>NHSO<sub>4</sub>·SnMe<sub>3</sub>Cl [5, 6]. The value of the quadrupole splitting ( $QS = 3.67 \text{ mm}\cdot\text{s}^{-1}$ ) of this compound is consistent with a trans coordinated SnMe<sub>3</sub> residue [12, 13] allowing to suggest while considering the complex-anion  $[\text{HO}\cdot\text{SO}_3\cdot\text{SnMe}_3\text{Cl}]^-$  a dimeric structure similar to the one reported for Bu<sub>4</sub>NHSO<sub>4</sub>·SnMe<sub>3</sub>Cl (Figure 6).

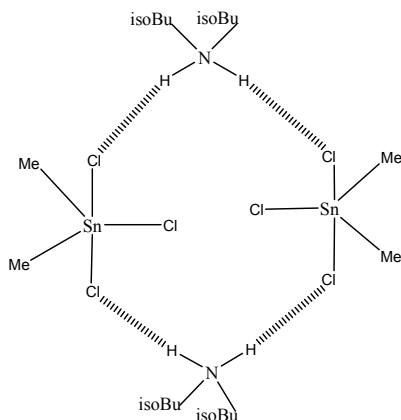
When the cation, through NH---O or NH---Cl hydrogen bonds is involved, supramolecular architectures are obtained.



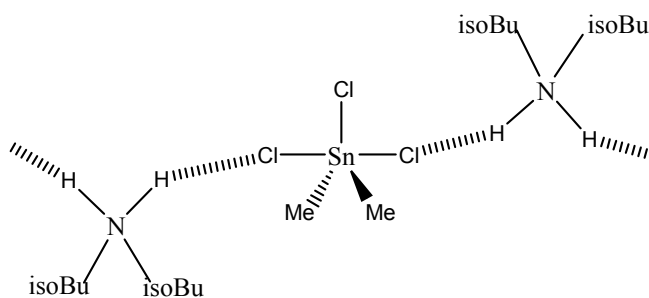
**Figure 6.** Supramolecular structures obtained from dimeric  $[\text{HO}\cdot\text{SO}_3\cdot\text{SnMe}_3\text{Cl}]^-$  anions

**(isoBu)<sub>2</sub>NH<sub>2</sub>SnMe<sub>2</sub>Cl<sub>3</sub> (H)**

The quadrupole splitting of **(F)** ( $3.19 \text{ mm}\cdot\text{s}^{-1}$ ) is consistent with a trigonal bipyramidal environment around the tin (IV) centre as yet reported in [18, 19] and allows to suggest a supramolecular architecture, when cations are involved through NH---Cl hydrogen bonds (infinite chains or oligomers). We have arbitrary reported the dimer and the infinite chain (Figures 7 and 8).



**Figure 7.** Structure of  $(\text{isoBu})_2\text{NH}_2\text{SnMe}_2\text{Cl}_3$  dimer



**Figure 8.** Part of the  $(\text{isoBu})_2\text{NH}_2\text{SnMe}_2\text{Cl}_3$  infinite chain

The wide absorption on the infrared spectra of all compounds containing a nonsymmetrical cation around  $2900 \text{ cm}^{-1}$  is due to hydrogen bonds involving the cation or HSO<sub>4</sub><sup>-</sup>.



## CONCLUSION

The structure of the studied adducts are discrete mainly or polymeric while considering the complex-anion. When the cations are involved, supramolecular structures are obtained. The anions are chelating, monocoordinating or bidentate ligands. Tetrahedral  $\text{SnMe}_2\text{Cl}_2$  has been characterized spectroscopically.

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## REFERENCES

1. Evans, C.J., Karpel, S.: Organotin Compounds in Modern Technology, *J. Organomet. Chem. Library*, **16**, Elsevier, Amsterdam, **1985**;
2. Kapoor, R.N., Guillory, P., Schulte, L., Cervantes-Lee, F., Haiduc, I., Parkanyi, L., Pannell, K.H.: *Appl. Organomet. Chem.*, **2005**, **19**, 510;
3. Zhang, W.L., Ma, J.F., Jiang, H.: *Acta Cryst. Sect E*, **2006**, **62**, m460;
4. Molloy, K.C., Quill, K.C., Cunningham, D.C., Mc Ardle, P., Higgens, T.: *J. Chem. Soc. Dalton Trans.*, **1989**, 267;
5. Diop, C.A.K., Diop, L., Toscano, R.A.: *Main Group Met. Chem.*, **2002**, **25** (5), 327;
6. Diallo, W., Diassé-Sarr, A., Diop, L., Mahieu, B., Biesemans, M., Willem, R., Kociok-Köhn, G., Molloy, K.C.: *Scientific Study and Research*, **2009**, **10** (3), 207;
7. Sidibé, M., Lahlou, M., Diop, L., Mahieu, B.: *Main Group Met. Chem.*, **1998**, **21** (10), 605;
8. Diop, C.A.K., Okio, K.Y.A., Diop, L., Mahieu, B.: *Main Group Met. Chem.*, **2000**, **23** (9), 493;
9. Diassé-Sarr, A., Barry, A.H., Jouini, T., Diop, L., Mahieu, B., Mahon, M.F., Molloy, K.C.: *J. Organomet. Chem.*, **2004**, **689**, 2087;
10. Gueye, O., Qamar, H., Diop, L., Diop, C.A., Russo, U.: *Polyhedron*, **1993**, **12** (10), 1245;
11. Chevalier, B., Wattiaux, A., Bobet, J.L.: *J. Phys.: Condens. Matter*, **2006**, **18**, 1743;
12. Bancroft, M., Platt, R.H.: *Mössbauer Spectra in Inorganic Compounds: Structure and Bonding in Advanced Inorganic Chemistry and Radio Chemistry* (Emeleus, H.J., Sharpe, A.G. – editors), Academic Press, New York, **1972**, **15**, 110;
13. Parish, R.V., Platt, R.H.: *Inorg. Chim. Acta*, **1970**, **4**, 65;
14. Nakamoto, K.: *Infrared and Raman Spectra of Inorganic and Coordination Compounds*, John Wiley and Sons, 5th Edition, **1997**;
15. König, U.-C., Berkel, M., Hirsch, C., Preut, H., Mitchell, T.N.: *Acta Cryst., Sect C: Cryst. Struct. Comm.*, **2000**, **56**, e550;
16. Xu, T., Yang, S.-Y., Xie, Z.-X., Ng, S.W.: *Acta Cryst., Sect. E*, **2003**, **59**, m870;
17. Ng, S.W.: *Acta Cryst. Sect C: Cryst Struct. Comm.*, **1996**, **52**, 2990;
18. Ma, C., Han, Y., Zhang, R., Wang, D.: *Dalton Trans*, **2004**, 1832;
19. Calogero, S., Valle, G., Cecchi, P., Lobbia, G.G.: *Polyhedron*, **1996**, **15**, 1465.