

SYNTHESIS AND CHARACTERIZATION BY INFRARED AND MOSSBAUER SPECTROSCOPIES OF SOME NEW SnR₂ (R = Me, Ph, Bu) RESIDUE CONTAINING ARBOXYALKYLPHOSPHONATE ADDUCTS AND DERIVATIVES

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Abstract: Four new carboxyalkylphosphonate SnR₂ residue (R = Me, Ph, Bu) containing adducts and derivatives *i.e.* $\{(\text{Cy}_2\text{NH}_2)_3(\text{O}_2\text{CCH}_2\text{PO}_3)(\text{SnBu}_2\text{Cl}_2)\}$ (1), $\{[(\text{SnMe}_2\text{Cl})(\text{O}_2\text{CCH}_2\text{PO}_3\text{H}_2)]_4[\text{Cy}_2\text{NH}_2\text{Cl}]\}$ (2), $\{(\text{Me}_4\text{N})(\text{SnPh}_2\text{Cl})[\text{O}_2\text{C}(\text{CH}_2)_2\text{PO}_3\text{H}](\text{SnPh}_2)[\text{O}_2\text{C}(\text{CH}_2)_2\text{PO}_3\text{H}]\}$ (3) and $\{(\text{Cy}_2\text{NH}_2)_2(\text{O}_2\text{CCH}_2\text{PO}_3\text{H})(\text{SnPh}_2\text{Cl}_2)_2\}$ (4), have been synthesized from one-pot reactions carried out in solution. All compounds have been investigated by spectral techniques (infrared and Mossbauer). The spectral studies have evidenced presence of several characteristic bands, especially $\nu(\text{C}=\text{O})$, $\nu(\text{OH})$, $\nu(\text{CO}_2^-)$, $\nu(\text{PO}_3^{2-})$ vibrations coming from carboxyalkylphosphonate ions, with wide absorption due to the NH₂ groups coming from the dicyclohexylammonium counter ion (for 1, 2 and 4) and the intense doublet which show the presence of phenyl groups (for 3 and 4). In the solid state, the proposed structures are discrete or of infinite chain however hydrogen bonding patterns may occur. Event in this investigation is the presence, for compound 3, of two types of arrangement at Sn centers *viz.* an octahedron and a trigonal bipyramidal whose presence are ascertained by the Mossbauer parameters. The neutral or acidic carboxyalkylphosphonate ions exhibit a diversity of coordination behavior towards the Sn atoms: monochelating (carboxylate and phosphonate O-donor), monochelating through the carboxylate and unidentate coordinating O-donor through the phosphonic acid or acidic phosphonate, bichelating with chelations from carboxylate and acidic phosphonate, and unidentate from both the carboxylate and phosphonic acid.

Keywords: discrete and polymeric structures, octahedral or trigonal bipyramidal environments, supramolecular architectures

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1. INTRODUCTION

Organotin compounds have several applications in various fields such as agriculture, industry and medical sciences [1-5]. The isolation of new organotin (IV) compounds carried considerable efforts because they are of the potential class of biologically active materials. Indeed, they evidenced in the past, antidiabetic [6], antituberculosis [7], antibacterial [8], antimicrobial [9], anti-inflammatory [10], antitumor [11-13] and cardiovascular [14] activities. The carboxyalkylphosphonate complexes are used in organic syntheses as catalysts in esterification reactions [15, 16]. From a structural point of view they have tendency to give rise polymeric structures [17-19].

The presence of two functions *viz* carboxylate and phosphonate, makes carboxyalkylphosphonates polyfunctional ligands able to behave as an anion that can coordinate metal atoms generating polymeric structures in which it adopts polydentate coordination mode. Several investigation studies dealing with carboxyalkylphosphonate complexes have previously been isolated and characterized [20-28]. The Dakar group has already been involved in studies by describing, using FT-IR, FT-Raman and Mossbauer spectroscopies, the structure of the complex $\{\text{SnMe}_2\text{Cl}[\text{O}_2\text{CCH}_2\text{PO}_3\text{H}]\}$ [29].

In the dynamic of widening our contribution in the field of organotin(IV), and understanding the behavior of carboxyalkylphosphonate, the reactions between $\text{HO}_2\text{CCH}_2\text{PO}_3\text{H}_2$ or $\text{HO}_2\text{C}(\text{CH}_2)_2\text{PO}_3\text{H}_2$ and some diorganotin chloride precursors. The isolation of four new SnR_2 [$\text{R} = \text{Me}, \text{Ph}, \text{Bu}$] residue containing carboxyalkylphosphonate compounds, was promoted. Their composition and structures have been investigated by elemental analyses and spectral studies (FT-IR and Mossbauer).

2. EXPERIMENTAL SETUP

2.1. Salts synthesis

$(\text{Cy}_2\text{NH}_2)_2\text{O}_2\text{CCH}_2\text{PO}_3\text{H}\cdot 3\text{H}_2\text{O}$ (L_1) and $(\text{Me}_4\text{N})\text{HO}_2\text{C}(\text{CH}_2)_2\text{PO}_3\text{H}\cdot \text{H}_2\text{O}$ (L_2), were obtained by partial neutralization of the $\text{HO}_2\text{C}(\text{CH}_2)_n\text{PO}_3\text{H}_2$ acids ($n = 1, 2$) by Cy_2NH (99%) in water or Me_4NOH (25% as aqueous solution), respectively in 1:2 and 1:1 ratio.

2.2. Compounds synthesis

The studied compounds were obtained as white powders after a slow solvent evaporation on mixing:

- L_1 in ethanol with SnBu_2Cl_2 in ethanol in ratio 1:3 (1);
- Cy_2NH in ethanol with $\text{HO}_2\text{CCH}_2\text{PO}_3\text{H}_2$ in methanol and SnMe_2Cl_2 in ethanol in ratio 2:1:1 (2);
- L_2 in methanol with SnPh_3Cl in methanol in ratio 2:1 (3);
- L_1 in chloroform with SnPh_2Cl_2 in ethanol in ratio 2:1 (4).

All the mixtures were stirred around two hours before being submitted to a slow solvent evaporation. The analytical data [% calculated and % found], reported below (Table 1) have allowed to suggest the formulae (Table 2).

Table 1. Analytical data.

Compound	Chemical composition [% mass]					
	C		H		N	
	Calc.	Found	Calc.	Found	Calc.	Found
1	55.93	55.56	9.39	9.42	4.25	4.17
2	22.26	21.74	4.27	4.20	0.92	0.89
3	42.56	42.49	4.41	4.35	1.46	1.43
4	50.45	50.35	6.01	6.03	2.35	2.30

Table 2. Compound and chemical formula.

Compound	Chemical formula
1	$\{(\text{Cy}_2\text{NH}_2)_3(\text{O}_2\text{CCH}_2\text{PO}_3)(\text{SnBu}_2\text{Cl}_2)\}$
2	$\{[(\text{SnMe}_2\text{Cl})(\text{O}_2\text{CCH}_2\text{PO}_3\text{H}_2)]_4[\text{Cy}_2\text{NH}_2\text{Cl}]\}$
3	$\{(\text{Me}_4\text{N})(\text{SnPh}_2\text{Cl})[\text{O}_2\text{C}(\text{CH}_2)_2\text{PO}_3\text{H}](\text{SnPh}_2)[\text{O}_2\text{C}(\text{CH}_2)_2\text{PO}_3\text{H}]\}$
4	$\{(\text{Cy}_2\text{NH}_2)_2(\text{O}_2\text{CCH}_2\text{PO}_3\text{H})(\text{SnPh}_2\text{Cl}_2)_2\}$

The results of the Mossbauer analyses are presented in Table 3.

Table 3. Results of the Mossbauer analyses of compounds 1-4.

Compound	Phases	IS (mm/s) (± 0.05)	QS (mm/s) (± 0.05)	Γ (mm/s) (± 0.04)
1	1	1.58	3.69	1.00
2	1	1.27	3.82	1.04
3	2	1.18	3.32	0.95
		0.45	1.80	0.93
4	1	0.43	1.77	1.01

Elemental analyses have been obtained at the ICMCB-Bordeaux University, France with a CHNS: Flash EA 1112 Thermofisher. Infrared spectra have been recorded at the CRPP-Bordeaux University, France using a Nicolet 6700 FT-IR spectrophotometer on diamond.

Mossbauer spectra were recorded at the ICMCB-Bordeaux, France on a liquid helium cryostat with a HALDER spectrometer. The chemicals were purchased from Aldrich Company-Germany- without any further purification.

3. RESULTS AND DISCUSSION

3.1. FT-IR spectroscopy

Compounds 1-5 have been investigated by FT-IR spectroscopy in ATR mode. In the past, FT-IR carboxylates and phosphonate vibration bands investigation have been reported [29]. The binding modes of the carboxylate moiety were investigated by FT-IR spectroscopy in ATR mode. Indeed, the magnitude of the $\Delta\nu(\text{COO})$ *i.e.* $\nu(\text{COO})_{\text{asym}} - \nu(\text{COO})_{\text{sym}}$ value is usually used to judge the coordination mode of carboxylate groups towards metal atoms [30-32]. Thus, the $\Delta\nu(\text{COO})$ value of 118 cm^{-1} in **1**, less than 150 cm^{-1} should be correlated to a carboxylate in chelation mode [33]. Moreover, the presence of carbonyl C=O vibration band at 1723 cm^{-1} diagnose dissymmetrical in binding, the global species adopting a chelation. In addition, the spectrum of **1** exhibits absorption bands that can be assigned to N-C and C-H bonds of the dicyclohexylammonium ion, and carboxy methyl phosphonate.

The presence of vibration band located in the region $3000-2500 \text{ cm}^{-1}$ which may be assigned to O-H and/or N-H stretching vibrations is very difficult to be attributed. Vibration bands situated at 1309 cm^{-1} and 1289 cm^{-1} correspond to C-N stretching and deformation vibrations of the dicyclohexylammonium. The rocking CH_3 and CH_2 vibrations expected about $1000-1100 \text{ cm}^{-1}$, are partially overlapped by stretching vibrations of the phosphonate which appear about 1129 and 1033 cm^{-1} , while their elongation vibrations are observed at 746 cm^{-1} . The carboxylate and phosphonate deformation vibration bands are observed at 783 and 588 cm^{-1} , respectively. The presence of both $\nu(\text{SnC}_2)_{\text{asym}}$ at 684 cm^{-1} and $\nu(\text{SnC}_2)_{\text{sym}}$ at 607 cm^{-1} is in accordance with a nonlinear SnC_2 group [34, 35].

The $\Delta\nu(\text{COO})$ value of 189 cm^{-1} in **2**, is correlated to a carboxylate in monodentate mode. The presence of carbonyl C=O vibration band at 1698 cm^{-1} evidenced a dissymmetrical binding, the global ion adopting chelation from the carboxylate. The spectrum of **2** exhibits absorption bands assignable to N-C and C-H bonds of the dicyclohexylammonium ion, and carboxy methyl phosphonate. Vibration bands situated at 1297 cm^{-1} and 1206 cm^{-1} correspond to C-N stretching and deformation vibrations of the dicyclohexylammonium. The shift of $\nu(\text{P=O})$ vibration band is also observed enabled by the coordination of the phosphonate moiety.

The rocking CH_3 and CH_2 vibrations expected about $1000-1100 \text{ cm}^{-1}$, are also partially overlapped by stretching vibrations of the phosphonate which appear at 1124 , 1085 and 1032 cm^{-1} . The elongation vibrations of CH_3 and CH_2 are observed about 722 cm^{-1} . The carboxylate and phosphonate deformation vibration bands are observed at 779 and 621 cm^{-1} , respectively. The presence of $\nu(\text{SnC}_2)_{\text{asym}}$ at 706 cm^{-1} and the absence of $\nu(\text{SnC}_2)_{\text{sym}}$ are in accordance with a linear SnC_2 group [30, 36].

The $\Delta\nu(\text{COO})$ value of 89 cm^{-1} in **3**, is in accordance with a carboxylate in chelation mode. The presence of carbonyl C=O vibration band at 1715 cm^{-1} evidences dissymmetry in the binding, the global species adopting a chelation from the carboxylate. The spectrum of compound **3** exhibits absorption bands assignable to N-C and C-H bonds of the dicyclohexylammonium ion, and carboxy ethyl phosphonate. The C-N stretching and deformation vibration bands of the dicyclohexylammonium are attributed to bands appearing at 1243 cm^{-1} and 1185 cm^{-1} ,

respectively. The rocking CH_3 and CH_2 vibrations expected about $1000\text{--}1100\text{ cm}^{-1}$, are overlapped by stretching vibrations of the phosphonate which appear about 1071 , 1017 and 997 cm^{-1} . The elongation vibrations of CH_3 and CH_2 are also overlapped by vibration bands characteristic of phenyl ligands, observed at 730 and 697 cm^{-1} corresponding to phenyl groups C–H and C=C elongations, respectively. The carboxylate and phosphonate deformation vibration bands are observed in order at 801 and 660 cm^{-1} ; the latter is partially overlapped by C–H and C=C elongations of phenyl groups. The presence of $\nu(\text{SnC}_2)_{\text{sym}}$ observed at 618 cm^{-1} is in accordance with a nonlinear SnC_2 group [34, 35].

The $\Delta\nu(\text{COO})$ value of 230 cm^{-1} in 4 higher than 200 cm^{-1} , is in accordance with a carboxylate in monodentate coordination mode. The presence of carbonyl C=O vibration band at 1720 cm^{-1} evidenced a pendent oxygen site from the carboxylate. The $\nu(\text{P=O})$ vibration band is shifted at 1120 cm^{-1} , describing coordination of the phosphonate ligand. Thus, the anion adopts a bridging bidentate coordination fashion through the carboxylate.

The spectrum of 4 ascertained absorption bands assignable to N–C and C–H bonds of the dicyclohexylammonium ion, and carboxy methyl phosphonate. The C–N stretching and deformation vibration bands of the dicyclohexylammonium are attributed to bands appearing at 1347 cm^{-1} and 1279 cm^{-1} , respectively. The rocking CH_3 and CH_2 vibrations expected about $1000\text{--}1100\text{ cm}^{-1}$, are overlapped by stretching vibrations of the phosphonate which appear in the region $1120\text{--}1013\text{ cm}^{-1}$. The elongation vibrations of CH_3 and CH_2 are also overlapped by vibration bands characteristic of phenyl ligands, observed at 735 and 697 cm^{-1} corresponding to phenyl groups C–H and C=C elongations, respectively. The carboxylate and phosphonate deformation vibration bands are observed in order at 817 and 588 cm^{-1} . The presence of $\nu(\text{SnC}_2)_{\text{sym}}$ observed at 630 cm^{-1} is in accordance with a nonlinear SnC_2 group [34, 35].

For compounds wherein the dicyclohexylammonium counter ion is present, absorption bands corresponding to NH_2 bending vibrations are overlapped by the carboxylate vibrations, the scissoring, bending vibrations of CH_2 group too. The same phenomenon is observed for vibrations corresponding to wagging or twisting, the bending vibrations out of plane of CH_2 groups.

Infrared characteristic absorption vibration bands evidence presence of all moieties which are present in the proposed formulae. Thus, the infrared investigations well corroborate the suggested formulae.

3.2. Mossbauer spectroscopy and molecular structures

Compounds 1–4 were also investigated by ^{119}Sn Mossbauer spectroscopy (Table 3). For 1, the Mossbauer parameters (Table 3) evidence one arrangement type at Sn atom. In the past, report for SnBu_2Cl_2 exhibits a quadrupole splitting of $3.38\text{ mm}\cdot\text{s}^{-1}$ describing SnBu_2 residues in a dissymmetrical *trans*-octahedral coordination fashion. Thus, the value of the quadrupole splitting, higher than $3.38\text{ mm}\cdot\text{s}^{-1}$ as well as the isomer shift [37] describes an octahedron at Sn center. Various SnBu_2 containing crystalline structures are known, to date [30, 34–36]. In the solid state, the FT-IR and Mossbauer data suggest a discrete structure with a chelating anion dissymmetrically coordinated to SnBu_2Cl_2 molecule (Figure 1); the counter ions interact with the complex-anion through hydrogen bonding patterns giving rise to a supramolecular topology.

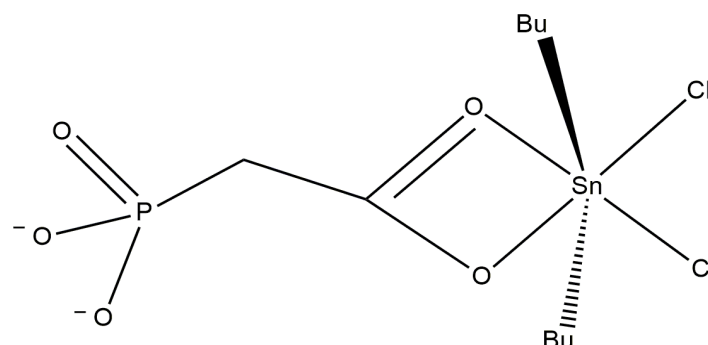


Fig. 1. Proposed structure for $(\text{Cy}_2\text{NH}_2)_3\text{O}_2\text{CCH}_2\text{PO}_3\cdot\text{SnBu}_2\text{Cl}_2$ (1).

For 2, the Mossbauer parameters (Table 3) confirm the presence of only *trans*-coordinated octahedral geometry at tin center [30, 36]. Indeed, previous reports for SnMe_2Cl_2 and $\text{SnMe}_2\text{O}_2\text{CCH}_2\text{PO}_3\text{H}$ complex-cation, which have quadrupole splitting of $3.56\text{ mm}\cdot\text{s}^{-1}$ and $3.83\text{ mm}\cdot\text{s}^{-1}$, describe structures wherein the arrangement at tin centers is

a dissymmetrical *trans*-coordinated octahedron [29, 38]. Therefore, our spectroscopic data suggests an infinite chain structure for the $\text{SnMe}_2\text{ClO}_2\text{CCH}_2\text{PO}_3\text{H}_2$ complex, in the solid state. In the structure the anion describes carboxylate chelation and phosphonate monodentate coordination modes (Figure 2).

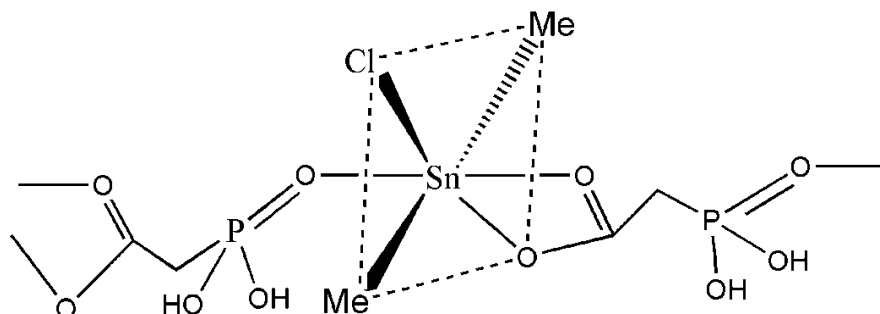


Fig. 2. Proposed structure for $\text{SnMe}_2\text{ClO}_2\text{CCH}_2\text{PO}_3\text{H}_2 \cdot 1/4\text{Cy}_2\text{NH}_2\text{Cl}$ (2).

For 3, the Mossbauer parameters evidence two arrangement types at Sn atoms *i.e.* trigonal bipyramidal and *cis*-octahedral coordination. The FT-IR and Mossbauer data (Table 3) allow to suggest, in the solid state, an infinite chain with alternating SnPh_2 and the SnPh_2Cl moieties bridged by the anion describing carboxylate monochelation *cis*-chelating the SnPh_2 moiety, and phosphonate monocoordination *trans*-coordinating the SnPh_2Cl fragment; the phenyl groups are disposed in the basal planes (Figure 3). The adverse cations interact through electrostatic forces with the complex-anion.

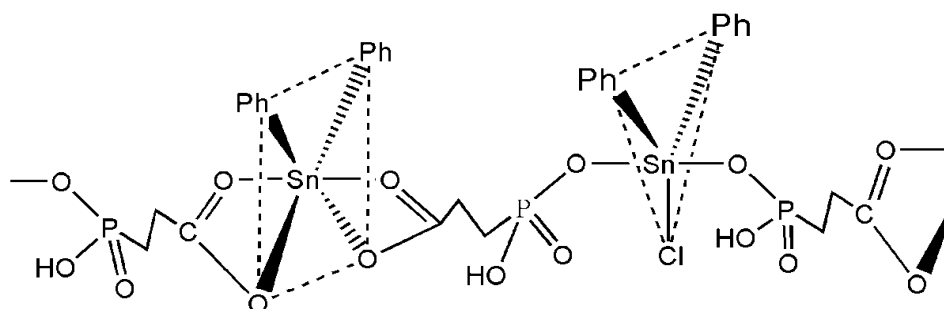


Fig. 3. Proposed structure for $(\text{Me}_4\text{N})(\text{SnPh}_2\text{Cl})\text{O}_2\text{C}(\text{CH}_2)_2\text{PO}_3\text{H} \cdot \text{SnPh}_2\text{O}_2\text{C}(\text{CH}_2)_2\text{PO}_3\text{H}$ (3).

For 4, the Mossbauer quadrupole splitting value is consistent with *cis*-octahedral coordination. The spectroscopic data suggests for the complex-anion, in the solid state, a discrete structure describing a monodentate carboxylate and phosphonate bridging tridentate ligand coordinated to two SnPh_2Cl_2 molecules, wherein phenyl groups are in *cis*-positions (Figure 4).

The counter ions interact with the complex-anion through hydrogen bonding patterns affording a supramolecular structure.

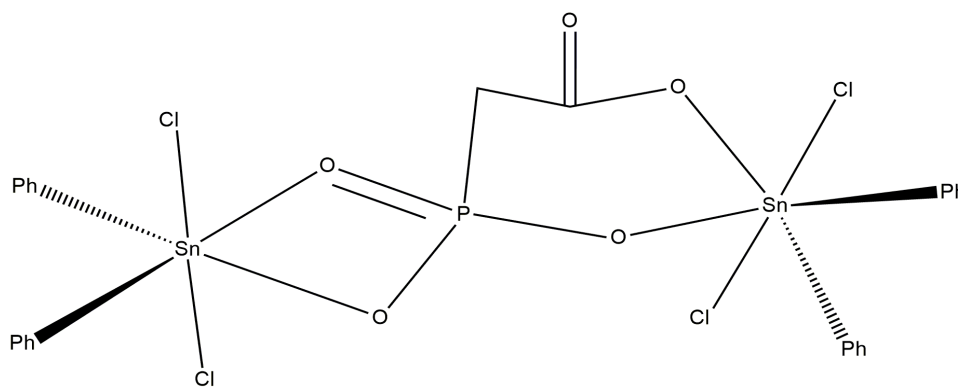


Fig. 4. Proposed structure for $(\text{Cy}_2\text{NH}_2)_2\text{O}_2\text{CCH}_2\text{PO}_3\text{H} \cdot 2\text{SnPh}_2\text{Cl}_2$ (4).

4. CONCLUSIONS

Carried out in solution, the one-pot reactions between the carboxyalkylphosphonate salts, $(\text{C}_2\text{NH}_2)_2\text{O}_2\text{CCH}_2\text{PO}_3\text{H}\cdot 3\text{H}_2\text{O}$ or $(\text{Me}_4\text{N})\text{HO}_2\text{C}(\text{CH}_2)_2\text{PO}_3\text{H}\cdot \text{H}_2\text{O}$, and organotin(IV) precursors led to the isolation of four adducts and derivatives whose characterizations were merged using FT-IR and Mossbauer techniques. The studied adducts and derivatives have a discrete or an infinite chain structure. The carboxyalkylphosphonate acidic or neutral ligands behave as a monochelating, monochelating and monodentate or bichelating. The environments around the tin centers are *cis*-, *trans*-octahedral or trigonal bipyramidal. When the counter cations are involved in hydrogen bonding interactions, a supramolecular architecture is obtained.

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REFERENCES

- [1] Koch, B., Basu Baul, T.S., Chatterjee, A., A cell proliferation inhibition and antitumor activity of novel alkyl series of diorganotin (IV) Compounds Investigational, Journal of Applied Toxicology, vol. 28, 2008, p. 430-438.
- [2] Koch, B., Basu Baul, T.S., Chatterjee, A., P53-dependent antiproliferative and antitumor effect of novel alkyl series of diorganotin (IV) Compounds, Investigational New Drugs, vol. 27, 2009, p. 319-326.
- [3] Basu Baul, T.S., Paul, A., Pellerito, L., Scopelliti, M., Singh, P., Verma, P., Duthie, A., De Vos, D., Tiekink, E. R. T., Dibutyltin(IV) complexes containing arylazobenzoate ligands: chemistry, in vitro cytotoxic effects on human tumor cell lines and mode of interaction with some enzymes, Investigational New Drugs, vol. 29, 2011, p. 285-299.
- [4] Basu Baul, T.S., Paul, P., Verma, Singh, P., Molecular docking of dichlorodiorgano [N-(2-pyridylmethylene)arylamine]tin(IV) complexes with some enzymes, Journal of Computational Methods in Molecular Design, vol. 1, no. 3, 2011, p. 11-23.
- [5] Yousif, E., Synthesis, spectroscopic studies and fungicidal activity of some diorganotin(IV) with 2-[(phenylcarbonyl)amino]propanoate, Journal of King Saud University - Science, vol. 24, 2012, p. 167-170.
- [6] Debnath P., Singh K.S., Singh K.K., Singh S.S., Sieroń L., Maniukiewicz W., Di-butyltin(IV) complexes with azo-carboxylates: synthesis, characterization, crystal structures and their anti-diabetic assay, New Journal of Chemistry, vol. 44, 2020, p. 5862-5872.
- [7] Kovala-Demertzi, D., Dokorou, V., Ciunik, Z., Kourkoumelis, N., Demertzis, M.A., Organotin mefenamic complexes—preparations, spectroscopic studies and crystal structure of a triphenyltin ester of mefenamic acid: novel antituberculosis agents, Applied Organometallic Chemistry, vol. 16, no. 7, 2002, p. 360-368.
- [8] Nath, M., Pokharia, S., Yadav, R., Organotin(IV) complexes of amino acids and peptides, Coordination Chemistry Reviews, vol. 215, no. 1, 2001, p. 99-149.
- [9] Nath, M., Pokharia, S., Eng, G., Song, X., Kumar, A., Gielen, M., Willem, R., Biesemans, M., New trimethyltin(IV) derivatives of dipeptides: synthesis, characteristic spectral studies and biological activity, Applied Organometallic Chemistry, vol. 18, no. 9, 2004, p. 460-470.
- [10] Nath, M., Pokharia, S., Eng, G., Song, X., Kumar, A., Diorganotin(IV) derivatives of dipeptides containing at least one essential amino acid residue: synthesis, characteristic spectral data, cardio-vascular, and anti-inflammatory activities, Synthesis and Reactivity in Inorganic and Metal-Organic Chemistry, vol. 34, no. 10, 2004, p. 1689-1708.
- [11] Camacho, C.C., de Vos, D., Mahieu, B., Gielen, M., Kemmer, M., Biesemans, M., Willem, R., Organotin(IV) derivatives of 3,4-(methylenedioxy)phenylacetic acid: synthesis, spectroscopic characterization and in vitro antitumor properties, Main Group Metal Chemistry, vol. 23, no. 7, 2000, p. 381-386.
- [12] Gielen, M., Biesemans, M., de Vos, D., Willem, R., Synthesis, characterization and in vitro anti-tumor activity of di- and triorganotin derivatives of polyoxa- and biologically relevant carboxylic acids, Journal of Inorganic Biochemistry, vol. 79, no. 1-4, 2000, p. 139-145.
- [13] Zhang, Y.Y., Zhang, R.F., Zhang, S.L., Cheng, S., Li, Q.L., Ma, C.L., Syntheses, structures and anti-tumor activity of four new organotin(IV) carboxylates based on 2-thienylselenoacetic acid, Dalton Transactions, vol. 45, no. 20, 2016, p. 8412-8421.
- [14] Nath, M., Pokharia, S., Eng, G., Song, X., Kumar, A., Comparative study of structure-activity relationship of di- and tri-organotin(IV) derivatives of amino acid and peptides, Journal of Organometallic Chemistry, vol. 669, no. 1-2, 2003, p. 109-123.

- [15] Chandrasekhar, V., Nagendran, S., Bakar, V., Organotin assemblies containing SnO bonds, *Coordination Chemistry Reviews*, vol. 235, no. 1-2, 2002, p. 1-52.
- [16] Song, S.Y., Ma, J.F., Yang, J., Gao, L.L., Su, Z.M., Synthesis of an organotin oligomer containing a heptanuclear tin phosphonate cluster by debenzoylation reactions: X-ray crystal structure of $\{Na_6(CH_3OH)_2(H_2O)\} \cdot \{(BzSn)_3(PhPO_3)_5(\mu_3O)(CH_3O)_2Bz_2Sn\} \cdot CH_3OH$, *Organometallics*, vol. 26, no. 8, 2007, p. 2125-2128.
- [17] Zhang, R., Wu, J., Ma, C., Hydrothermal Synthesis and Characterization of Trimethyltin(IV) Derivatives with 2-Carboxyethylphosphonic and Benzylphosphonic acid: X-ray Crystal Structures of 2D Network Polymers, *Journal of inorganic and Organometallic Polymers*, vol. 20, no. 2, 2010, p. 405-410.
- [18] Mautner, F.A., Speed, S., El Fallah, M.S., Vicente, R., Copper (II) complexes derived from 3-phosphonopropionic acid: Crystal structures and magnetic behaviour, *Polyhedron*, vol. 81, 2014, p. 1-5.
- [19] Boye, M.S., Diasse-Sarr, A., Grosjean, A., Guionneau, P., Poly[μ -diaqua(μ -4-Carboxylatoethylphosphonato)(μ -4-carboxymethylphosphonato)pentadecamethylpentatin (IV)], *Acta Crystallographica*, vol. E69, 2013, p. m110- m111.
- [20] Anillo, A., Altomare, A., Moliterni, A.G.G., Bauer, E.M., Bellitto, C., Colapietro, M., Portalone, G., Righini, G., Hydrothermal synthesis, structural characterization and magnetic studies of the new pillared microporous ammonium Fe(III) carboxyethylphosphonate: $[NH_4][Fe_2(OH)\{O_3P(CH_2)_2CO_2\}_2]$, *Journal of Solid State Chemistry*, vol. 178, no. 1, 2005, 178, p. 306-313.
- [21] Gomez-Alcantara, M.M., Aranda, M.A.G., Olivera-Pastor, P., Beran, P., Garcia-Munoz, J.L., Cabeza, A., Layered and pillared metal carboxyethylphosphonate hybrid compounds, *Dalton Transactions*, vol. 2006, 2006, p. 577-585.
- [22] Ying, S.M., Chen, Y., Lin, J.Y., Zhou, G.P., Wu, J.H., Bis[μ -(2-carboxylatoethyl) phosphonato]bis[aqua(2,2'-bipyridine)cobalt(II)], *Acta crystallographica*, vol. E63, no. 11, 2007, m2862-m2862;
- [23] Ying, S.M., Chen, Y., Luo, Q.Y., Xu, Y.P., Liu, D.S., Bis(μ -carboxylatoethylphosphonato)bis[aqua(2,2'-bipyridine)manganese(II)], *Acta Crystallographica*, vol. E64, 2008, p. m166.
- [24] Chen, K., Sun, Z.G., Zhu, Y.Y., Liu, Z.M., Tong, F., Dong, D.P., Li, J., Jiao, C.Q., Li, C., Wang, C. P., Syntheses, crystal structures, and luminescence properties of three novel lead carboxyphosphonates with 3D framework structures using rigid aromatic carboxylic acids as second organic ligands, *Crystal Growth & Design*, vol. 11, 2011, p. 4623-4631.
- [25] Li, X.M., Chen, Y.G., Su, C., Zhou, S., Tang, Q., Shi, T., Functionalized pentamolybdodiphosphate - based inorganic-organic hybrids: synthesis, structure, and properties, *Inorganic Chemistry*, vol. 52, no. 19, 2013, p. 11422-11427.
- [26] Piskula, Z., Kubicki, M., Lis, S., The structural and spectroscopic studies of UO_2^{2+} complexes with diethylbenzylphosphonate and diethyl (carboxymethyl) phosphonate in solution and in the solid state, *Polyhedron*, vol. 62, 2013, p. 243-249.
- [27] Singh, U. P., Narang, S., A supramolecular approach towards the construction of molecular salts using phosphonic acid and pyrazole, *CrystEngComm*, vol. 16, 2014, p. 7777-7789.
- [28] Kofenstein, R., Arnold, M., Robl, C., Crystal structure and characterization of two layered copper(ii) coordination polymers with anions of 3-phosphonopropionic acid and (RS)-2-phosphonobutyric acid, *Zeitschrift für anorganische und allgemeine Chemie*, vol. 644, no. 4, 2018, p. 205-214.
- [29] Diasse-Sarr, A., Diop, L., Synthèse et étude par spectroscopie Infrarouge, Raman et Mossbauer de dérivés du type SnR_2A et $(SnR_2Cl)A$ ($R=Me, Bu; A=SeO_3, CH_3PO_3, O_2CCH_2PO_3H, H_3PO_4$), *Journal de la Société OUEST Africaine de Chimie*, vol. 9, 2000, p. 117-125.
- [30] Diop, T., Ndiolene, A., Diop, M. B., Boye, M. S., van der Lee, A., Dumitru, F., Diop, C. A. K., Sidibe, M., Synthesis, spectral (FT-IR, $^1H, ^{13}C$) studies and crystal structure of $[(2,6-CO_2)_2C_5H_3NSnBu_2(H_2O)]_2 \cdot CHCl_3$, *Zeitschrift für Naturforschung*, vol. b76, no. 2, 2021, p. 127-132.
- [31] Basu Baul T. S., Paul A., Pellerito L., Scopelliti M., Singh P., Verma P., Duthie A., de Vos D., Tiekink E. R. T., Dibutyltin(IV) complexes containing arylazobenzoate ligands: chemistry, in vitro cytotoxic effects on human tumor cell lines and mode of interaction with some enzymes, *Investigational New Drugs*, vol. 29, no. 2, 2011, p. 285-299.
- [32] Muhammad, N., Ikram, M., Wadood, A., Rehman, S., Shujah, S., Erum, Ghufuran, M., Rahim, S., Shah, M., Schulzke, C., Synthesis, crystal structure, DNA binding and molecular docking studies of Zinc(II) carboxylates, *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, vol. 190, 2018, p. 368-377.
- [33] Li, W., Du, D., Liu, S., Zhu, C., Sakho, A. M., Zhu, D., Xu, L., Self-assembly of a novel 2D network polymer: Syntheses, characterization, crystal structure and properties of a four-tin-nuclear 36-membered diorganotin(IV) macrocyclic carboxylate, *Journal of Organometallic Chemistry*, vol. 695, 2010, p. 2153-2159.
- [34] Nath, M., Singh, H., Eng, G., Song, X., Mossbauer spectral studies of di- and triorganotin(IV) histidinylleucinates, *Hyperfine Interact*, vol. 185, 2008, p. 69-79.

- [35] Du, D., Jiang, Z., Liu, C., Sakho, A. M., Zhu, D., Xu, L., Macrocyclic organotin(IV) carboxylates based on benzenedicarboxylic acid derivatives: Syntheses, crystal structures and antitumor activities, *Journal of Organometallic Chemistry*, vol. 696, 2011, p. 2549-2558.
- [36] Hanif, M., Hussain, M., Ali, S., Bhatti, M. H., Ahmed, M. S., Mirza, B., Stoeckli-Evans, H., In vitro biological studies and structural elucidation of organotin(IV) derivatives of 6-nitropiperonylic acid: Crystal structure of $\{[(\text{CH}_2\text{O}_2\text{C}_6\text{H}_2(o\text{-NO}_2)\text{COO})\text{SnBu}_2]_2\text{O}\}_2$, *Polyhedron*, vol. 29, no. 1, 2010, p. 613-619.
- [37] Abdellah, M. A., Hadjikakou, S. K., Hadjiliadis, N., Kubicki, M., Bakas, T., Kourkoumelis, N., Simos, Y. V., Karkabounas, S., Barsan, M. M., Butler, I. S., Synthesis, Characterization, and biological studies of organotin(IV) derivatives with o- or p-hydroxybenzoic acids, *Bioinorganic Chemistry and Applications*, vol. 2009, 2009, ID 542979.
- [38] Karpati, S., Szalay, R., Csaszar, A. G., Suveg, K., Nagy, S., Influence of intermolecular interactions on the mossbauer quadrupole splitting of organotin(IV) compounds as studied by DFT calculations, *The Journal of Physical Chemistry A*, vol. 111, no. 50, 2007, p. 13172-13181.