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The different behaviour of the di-2-pyridylketone 2-thenoylhydrazone in two organotin compounds. Synthesis, X-ray structure and biological activity ☆

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Abstract

Two organotin compounds $[SnPh(dpt)Cl_2]$ (**1**) and $[SnPh_3Cl(OH_2)] \cdot Hdpt$ (**2**) (Hdpt = di-2-pyridylketone 2-thenoylhydrazone) have been synthesized and characterized by IR spectroscopy and X-ray diffraction. Hdpt behaves differently in the two compounds: it is deprotonated and ONN tridentate in **1** and uncoordinated in **2**, where pairs of hydrogen-bonded $[SnPh_3Cl(OH_2)]$ and Hdpt molecules are present. The tin environment is octahedral in **1** and trigonal bipyramidal in **2**. Compound **2** has shown good antimicrobial activity against Gram-positive bacteria and moulds in vitro. Neither compound showed genotoxic properties.

Keywords: Tin; X-ray structure; Hydrazone complex

1. Introduction

The chemical, structural, and, more recently, biological properties of organotin compounds have been a continuing subject of study in this laboratory [1,2]. Within this context, and in connection with our investigations on organotin and transition metal complexes of 2,6-diacetylpyridine bis(acylhydrazones) [2,3], it was decided to examine monoacylhydrazones as ligands to tin [4]. In view of their weaker chelating capability compared to bis(acylhydrazones), they should increase the biological activity of the tin species.

In the present paper we report the synthesis, the spectroscopic characterization, the X-ray crystal structure, and the antimicrobial activity of two organotin compounds derived from di-2-pyridylketone 2-thenoylhydrazone (Hdpt), namely $[SnPh(dpt)Cl_2]$ (**1**) and $[SnPh_3Cl(OH_2)] \cdot Hdpt$ (**2**). Since Hdpt contains a hydrazide-hydrazone chain and a pyridine moiety, which are often associated with genotoxic properties [5,6], DNA-damaging activity and mutagenicity have been also tested.

2. Experimental section

2.1. Materials and methods

All reactants and solvents were reagent grade. Dichlorodiphenyltin and chlorotriphenyltin were purchased from Strem Chemical Co., di-2-pyridylketone and 2-thiophenehydrazide from Aldrich-Chemie, 2-acetylaminofluorene, chloramphenicol, methyl methanesulfonate, *N*-methyl-*N'*-nitro-*N*-nitrosoguanidine, and mitomycin C from Fluka; Aroclor 1254 from Monsanto Co.

Elemental C, H, and N analyses were carried out on a Carlo Erba CHNS-O EA1108 Elemental Analyzer. IR spectra (4000–400 cm^{-1}) in KBr discs were recorded on a Nicolet 5PC FT-IR spectrometer, EI mass spectra were performed with a Finnigan-SSQ710 spectrometer, electronic spectra (900–200 nm) with a Kontron Uvikon 860 spectrophotometer, and ^1H NMR spectra with a Bruker AC 300 instrument. Chemical shifts are in ppm

☆ Dedicated to Professor Fausto Calderazzo on the occasion of his 65th birthday in recognition of his important contributions to organometallic chemistry, and as a mark of friendship.

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referred to tetramethylsilane. Melting points were obtained with a Gallenkamp MFB-595 apparatus in open capillaries and are uncorrected.

2.2. Synthesis

2.2.1. Di-2-pyridylketone 2-thenoylhydrazone (Hdpt)

Di-2-pyridylketone (0.1 g, 0.54 mmol) was dissolved in absolute ethanol (30 ml) with an equimolar amount of 2-thiophene hydrazide. The solution was then heated under reflux for 2 h and the solvent evaporated off partially under reduced pressure. A pale-yellow solid was isolated at room temperature (m.p. 151–152°C, 80% yield). Anal. Found: C, 62.51; H, 4.01; N, 18.71. $C_{16}H_{12}N_4OS$ calc.: C, 62.34; H, 3.90; N, 18.67%. MS: *m/e* (assignment, rel. int. (%)): 308 (M^+, 5), 197 ($M - C_5H_3OS$, 75), 169 ($M - C_5H_3N_2OS$, 100). NMR δ_H: 11.22 (1H, s, D_2O exchangeable), 8.80 (1H, d, $J = 4$ Hz), 8.62 (1H, d, $J = 4$ Hz), 8.08 (1H, d, $J = 8$ Hz), 7.82 (3H, m), 7.59 (2H, br), 7.37 (2H, m), 7.14 (1H, t, $J = 4$ Hz). IR (cm^{-1}): 3076 m, ν(NH); 1650 vs, ν(C=O); 1586 ms and 1583 ms, ν(C=N); 1512 m, amide II, 1384 m, amide III. UV: 272 nm ($\varepsilon = 33.200$), 325 nm ($\varepsilon = 17.700$), 396 nm ($\varepsilon = 900$).

2.2.2. [SnPh(dpt)Cl$_2$] (1)

Hdpt (0.1 g, 0.32 mmol) was dissolved in absolute ethanol (30 ml) with an equimolar amount of dichlorodiphenyltin and the resultant solution was heated under reflux for 0.5 h. After slow evaporation of the solvent, yellow crystals were isolated (m.p. 138–141°C). IR (cm^{-1}): 1585 m and 1583 m, ring, ν(C=N); 1522 ms, amide II; 1384 vs, amide III.

2.2.3. [SnPh$_3$Cl(OH$_2$)] · Hdpt (2)

A similar procedure was used for **2** (yellow crystals, dec. 296–300°C). IR (cm^{-1}): 3075 m, ν(NH); 1655 vs, ν(C=O); 1585 ms and 1583 m, ring, ν(C=N); 1512 m, amide II; 1384 m, amide III.

2.3. X-ray data collection, structure determination and refinement of compounds 1 and 2

All X-ray diffraction measurements were carried out at room temperature on a computer-controlled Siemens AED diffractometer using Cu Kα radiation ($\lambda = 1.54178$ Å) for **1** and Mo Kα radiation ($\lambda = 0.71069$ Å) for **2**. Automatic routines to search for, centre, and index reflections, in conjunction with reduced cell calculations, yielded a primitive triclinic cell for **1** and a primitive monoclinic cell for **2**. For **1** the ambiguity in the space group, $P1$ or $P\bar{1}$, was resolved by analysis of intensity statistics which strongly suggested the centric space group $P\bar{1}$ to be correct, while for **2** the observed systematic absences $h0l$, $h + l$ odd, and $0k0$, k odd, are consistent with the space group $P2_1/n$. Table 1 lists the unit-cell dimensions for both compounds together with details of data collection and structural analysis. No correction for crystal decay or loss of alignment was found to be necessary. The data were processed with the peak-profile analysis procedure following Lehmann and Larsen [7] and the structure amplitudes were obtained after the usual Lorentz and polarization reduction. A correction for absorption effects was applied according to the method of Walker and Stuart [8].

Table 1
Crystallographic data and data collection and structure analysis summary for compounds **1** and **2**

	1	**2**
Formula	$C_{22}H_{16}Cl_2N_4OSSn$	$C_{34}H_{29}ClN_4O_2SSn$
Molecular weight	574.1	711.8
Crystal system	Triclinic	Monoclinic
Space group	$P\bar{1}$	$P2_1/n$
a (Å)	14.378(3)	18.278(7)
b (Å)	9.820(3)	18.207(7)
c (Å)	8.700(2)	9.822(4)
α (°)	108.14(5)	90
β (°)	93.33(2)	96.65(2)
γ (°)	96.95(3)	90
V (Å^3)	1152.8(6)	3247(2)
Z	2	4
D_c (g cm^{-3})	1.654	1.456
$F(000)$	568	1440
μ (cm^{-1})	119.8	9.7
Scan mode	$\theta - 2\theta$	$\theta - 2\theta$
2θ range (°)	6–135	6–54
Collection region	$\pm h, \pm k, l$	$\pm h, k, l$
No. of data collected	4303	7779
No. of unique obs. reflections	3957	3924
Criterion for observation	$I > 2\sigma(I)$	$I > 2.5\sigma(I)$
No. of parameters varied	348	500
Max height in final $\Delta\rho$ map (e Å^{-3})	1.38	0.54
R	0.0448	0.0342
R_w	0.0575	0.0457

Both structures were solved by a combination of direct methods and heavy-atom techniques and refined by full-matrix least-squares procedures to minimize the quantity $\Sigma w(|F_o| - |F_c|)^2$ with weights derived from $w = k/[\sigma^2(F_o) + gF_o^2]$. For both **1** and **2** all non-hydrogen atoms were refined using anisotropic thermal parameters, whereas the hydrogen atoms, all located in difference Fourier maps, were included with isotropic values. In both compounds the thienyl ring was found disordered at the S and C(14) positions, the evidence for this being reflected in a smeared electron density distribution at the two sites as well as in abnormal

thermal parameters for the two atoms. A reasonable model for the disorder was obtained by considering for each ring two images related to each other by a pseudo twofold axis passing through C(13) and the centre of gravity of the C(15)–C(16) bond and such that S and C(14) are interchanged between the two sites, the compositions of which (0.6/0.4 for **1** and 0.55/0.45 for **2**) were determined by refining the occupancy factors. Neutral atom scattering factors were used and anomalous dispersion corrections were applied to all non-hydrogen atoms. Calculations were performed on a Gould-Powernode 6040 computer using the SHELX76 [9], ABSORB [10], PARST [11], and ORTEP [12] program packages.

Final atomic parameters are given in Table 2 for **1** and in Table 3 for **2**. Bond distances and angles are listed in Tables 4 and 5 for **1** and **2**, respectively. These data and supplementary material comprising H-atom coordinates and anisotropic temperature factors have been deposited at the Cambridge Crystallographic Data Centre.

Table 2
Compound **1**: atomic coordinates ($\times 10^4$) and equivalent isotropic displacement parameters ($Å^2 \times 10^4$) (one-third trace of the diagonalized matrix), with e.s.d.s in parentheses

Atom	x	y	z	U_{eq}
Sn	2264.7(2)	872.8(4)	1264.8(4)	400(1)
Cl(1)	3780(1)	1880(2)	591(2)	584(6)
Cl(2)	864(1)	−677(2)	1626(2)	530(5)
O	2965(3)	570(4)	3304(4)	481(13)
S	4122(2)	−2643(3)	3963(3)	643(8)
N(1)	1847(3)	−59(5)	−1412(5)	435(15)
N(2)	2142(4)	−4507(5)	−2763(7)	708(23)
N(3)	2770(3)	−1231(4)	391(5)	427(15)
N(4)	3216(3)	−1667(5)	1540(5)	456(16)
C(1)	1430(4)	662(6)	−2261(7)	473(20)
C(2)	1215(4)	83(7)	−3926(7)	561(23)
C(3)	1423(4)	−1276(7)	−4698(8)	560(23)
C(4)	1848(4)	−2021(6)	−3830(7)	502(20)
C(5)	2062(3)	−1389(5)	−2157(6)	421(18)
C(6)	2576(3)	−2044(5)	−1091(6)	418(17)
C(7)	2821(4)	−3535(6)	−1738(7)	504(20)
C(8)	3683(5)	−3858(8)	−1321(9)	659(28)
C(9)	3862(9)	−5270(11)	−2048(13)	1059(48)
C(10)	3203(11)	−6243(11)	−3121(14)	1310(60)
C(11)	2350(9)	−5845(9)	−3453(13)	1141(49)
C(12)	3278(3)	−667(6)	2977(6)	430(19)
C(13)	3739(3)	−1026(6)	4324(6)	451(19)
C(14)	3922(2)	29(5)	6112(5)	524(15)
C(15)	4432(4)	−943(8)	6867(8)	590(25)
C(16)	4538(5)	−2237(9)	5870(10)	683(30)
C(17)	1642(4)	2821(5)	1827(6)	456(18)
C(18)	2095(6)	4049(7)	1579(10)	715(30)
C(19)	1644(7)	5225(8)	1711(12)	867(39)
C(20)	742(7)	5212(9)	2075(14)	869(41)
C(21)	268(7)	4001(11)	2416(18)	1045(53)
C(22)	743(5)	2830(8)	2257(11)	766(33)

Table 3
Compound **2**: atomic coordinates ($\times 10^4$) and equivalent isotropic displacement parameters ($Å^2 \times 10^4$) (one-third trace of the diagonalized matrix), with e.s.d.s in parentheses

Atom	x	y	z	U_{eq}
Sn	856.9(2)	8129.0(2)	2316.5(3)	465(1)
Cl	1187(1)	9188(1)	928(2)	851(6)
S	2025(1)	4596(1)	4628(3)	854(9)
O(1)	1371(2)	6031(2)	4676(4)	656(13)
O(2)	455(2)	7112(2)	3509(3)	512(11)
N(1)	−298(2)	7768(2)	5607(4)	528(14)
N(2)	−347(3)	5507(3)	8003(5)	757(18)
N(3)	386(2)	6482(2)	6289(4)	524(13)
N(4)	601(2)	5770(2)	6267(4)	570(14)
C(1)	−357(3)	8493(3)	5483(6)	619(20)
C(2)	−367(3)	8976(3)	6561(7)	734(22)
C(3)	−342(3)	8684(3)	7856(7)	744(23)
C(4)	−299(3)	7934(3)	8015(5)	653(20)
C(5)	−264(2)	7490(3)	6877(4)	496(15)
C(6)	−129(3)	6683(3)	6999(4)	517(15)
C(7)	−567(3)	6206(3)	7823(5)	600(17)
C(8)	−1201(3)	6474(4)	8323(6)	789(24)
C(9)	−1596(4)	5996(5)	9063(8)	1007(31)
C(10)	−1374(5)	5288(5)	9252(8)	1063(34)
C(11)	−762(4)	5064(4)	8713(8)	1014(32)
C(12)	1116(2)	5587(3)	5439(5)	525(15)
C(13)	1353(2)	4813(2)	5485(5)	508(14)
C(14)	1004(1)	4157(1)	6404(3)	492(8)
C(15)	1513(3)	3533(3)	5849(6)	709(21)
C(16)	2003(3)	3743(3)	5030(6)	671(20)
C(17)	1523(2)	7378(3)	1356(5)	570(17)
C(18)	1455(4)	7292(4)	−53(7)	823(25)
C(19)	1929(6)	6848(5)	−682(11)	1095(36)
C(20)	2488(7)	6508(6)	125(19)	1440(66)
C(21)	2575(5)	6582(5)	1479(17)	1277(49)
C(22)	2086(4)	7014(4)	2133(9)	929(29)
C(23)	−289(2)	8279(2)	1722(4)	451(14)
C(24)	−783(3)	7684(3)	1547(5)	562(17)
C(25)	−1529(3)	7803(4)	1157(6)	760(22)
C(26)	−1795(3)	8504(4)	947(6)	826(26)
C(27)	−1329(3)	9098(4)	1121(6)	760(23)
C(28)	−580(3)	8982(3)	1495(5)	604(19)
C(29)	1326(2)	8569(2)	4251(5)	496(15)
C(30)	1412(3)	9313(3)	4413(7)	744(23)
C(31)	1667(4)	9616(4)	5664(9)	1030(32)
C(32)	1842(4)	9181(4)	6765(8)	956(28)
C(33)	1769(3)	8446(4)	6647(7)	774(23)
C(34)	1506(3)	8136(3)	5401(5)	604(17)

2.4. Biological activity

2.4.1. Antimicrobial activity

The antimicrobial activity of the compounds was evaluated using previously reported procedures [2]. Antibacterial activity was tested against the following Gram-positive bacteria: *Bacillus subtilis* ATCC 6633, ATCC 6051, ATCC 9799, ATCC 9858; *B. brevis* BGSC 26A1, *B. cereus* ATCC 11778, ATCC 11966, *B. circulans* BGSC 16A1, *B. megaterium* BGSC 7A2, *B. natto* BGSC 27A1; *B. pumilus* BGSC 8E2 and several *B. thuringiensis* strains. *Escherichia coli* was used as a

Table 4
Bond distances (Å) and angles (°) with e.s.d.s in parentheses in Compound **1**

Sn–Cl(1)	2.462(2)	C(3)–C(4)	1.371(10)
Sn–Cl(2)	2.469(2)	C(4)–C(5)	1.392(7)
Sn–O	2.108(4)	C(5)–C(6)	1.493(8)
Sn–N(1)	2.236(4)	C(6)–C(7)	1.490(8)
Sn–N(3)	2.196(4)	C(7)–C(8)	1.373(10)
Sn–C(17)	2.141(6)	C(8)–C(9)	1.396(13)
O–C(12)	1.301(7)	C(9)–C(10)	1.343(15)
S–C(13)	1.686(6)	C(10)–C(11)	1.374(20)
S–C(16)	1.638(8)	C(12)–C(13)	1.470(9)
N(1)–C(1)	1.336(8)	C(13)–C(14)	1.564(6)
N(1)–C(5)	1.347(7)	C(14)–C(15)	1.543(10)
N(2)–C(7)	1.343(7)	C(15)–C(16)	1.329(10)
N(2)–C(11)	1.342(11)	C(17)–C(18)	1.383(10)
N(3)–N(4)	1.361(7)	C(17)–C(22)	1.366(9)
N(3)–C(6)	1.281(6)	C(18)–C(19)	1.369(12)
N(4)–C(12)	1.318(6)	C(19)–C(20)	1.352(15)
C(1)–C(2)	1.381(8)	C(20)–C(21)	1.419(16)
C(2)–C(3)	1.372(9)	C(21)–C(22)	1.381(14)
N(3)–Sn–C(17)	172.3(2)	N(1)–C(5)–C(4)	119.8(5)
N(1)–Sn–C(17)	100.7(2)	C(4)–C(5)–C(6)	124.6(5)
N(1)–Sn–N(3)	72.1(2)	N(1)–C(5)–C(6)	115.5(5)
O–Sn–C(17)	113.7(2)	N(3)–C(6)–C(5)	114.6(5)
O–Sn–N(3)	73.5(2)	C(5)–C(6)–C(7)	121.2(5)
O–Sn–N(1)	145.6(2)	N(3)–C(6)–C(7)	124.1(5)
Cl(2)–Sn–C(17)	95.8(2)	N(2)–C(7)–C(6)	114.7(5)
Cl(2)–Sn–N(3)	81.4(1)	C(6)–C(7)–C(8)	121.7(6)
Cl(2)–Sn–N(1)	87.3(1)	N(2)–C(7)–C(8)	123.6(6)
Cl(2)–Sn–O	88.3(1)	C(7)–C(8)–C(9)	117.4(8)
Cl(1)–Sn–C(17)	96.9(2)	C(8)–C(9)–C(10)	119.8(10)
Cl(1)–Sn–N(3)	85.5(1)	C(9)–C(10)–C(11)	119.4(13)
Cl(1)–Sn–N(1)	87.0(1)	N(2)–C(11)–C(10)	122.8(10)
Cl(1)–Sn–O	89.7(1)	O–C(12)–N(4)	126.5(5)
Cl(1)–Sn–Cl(2)	166.8(1)	N(4)–C(12)–C(13)	115.3(5)
Sn–O–C(12)	113.4(3)	O–C(12)–C(13)	118.2(5)
C(13)–S–C(16)	91.7(4)	S–C(13)–C(12)	119.7(4)
Sn–N(1)–C(5)	116.5(3)	C(12)–C(13)–C(14)	123.7(4)
Sn–N(1)–C(1)	122.7(4)	S–C(13)–C(14)	116.6(4)
C(1)–N(1)–C(5)	120.7(5)	C(13)–C(14)–C(15)	98.1(4)
C(7)–N(2)–C(11)	116.9(7)	C(14)–C(15)–C(16)	116.6(6)
Sn–N(3)–C(6)	121.1(4)	S–C(16)–C(15)	117.0(6)
Sn–N(3)–N(4)	116.1(3)	Sn–C(17)–C(22)	120.6(5)
N(4)–N(3)–C(6)	122.5(4)	Sn–C(17)–C(18)	120.7(5)
N(3)–N(4)–C(12)	110.4(4)	C(18)–C(17)–C(22)	118.2(6)
N(1)–C(1)–C(2)	121.4(5)	C(17)–C(18)–C(19)	120.8(7)
C(1)–C(2)–C(3)	118.4(6)	C(18)–C(19)–C(20)	120.9(9)
C(2)–C(3)–C(4)	120.3(6)	C(19)–C(20)–C(21)	120.0(9)
C(3)–C(4)–C(5)	119.3(5)	C(20)–C(21)–C(22)	117.4(10)
		C(17)–C(22)–C(21)	122.6(7)

Gram-negative bacterium. Antifungal activity was evaluated against yeasts (*Saccharomyces cerevisiae*, *Candida tropicalis*), moulds (*Aspergillus niger*) and phytopathogenic fungi (*Botrytis cinerea*, *Fusarium* spp., *Pythium irregulare*, *Sclerotinia minor*, *Stemphylium vesicarium*).

2.4.2. Genotoxicity

The *Bacillus subtilis rec*-assay was performed as described previously [2]. The *Salmonella*-microsome test was carried out by using *Salmonella typhimurium* TA 1535, TA 1537, TA 98, TA 100 and TA 102 strains following the pre-incubation procedure already re-

Table 5
Bond distances (Å) and angles (°) with e.s.d.s in parentheses in Compound **2**

Sn–Cl	2.477(2)	C(9)–C(10)	1.359(13)
Sn–O(2)	2.354(4)	C(10)–C(11)	1.355(12)
Sn–C(17)	2.123(5)	C(12)–C(13)	1.472(6)
Sn–C(23)	2.126(4)	C(13)–C(14)	1.669(5)
Sn–C(29)	2.147(5)	C(14)–C(15)	1.604(6)
S–C(13)	1.616(5)	C(15)–C(16)	1.327(9)
S–C(16)	1.604(6)	C(17)–C(18)	1.384(8)
O(1)–C(12)	1.230(6)	C(17)–C(22)	1.379(8)
N(1)–C(1)	1.330(7)	C(18)–C(19)	1.382(12)
N(1)–C(5)	1.341(6)	C(19)–C(20)	1.367(17)
N(2)–C(7)	1.340(7)	C(20)–C(21)	1.328(25)
N(2)–C(11)	1.354(10)	C(21)–C(22)	1.400(15)
N(3)–N(4)	1.355(6)	C(23)–C(24)	1.408(7)
N(3)–C(6)	1.288(6)	C(23)–C(28)	1.393(7)
N(4)–C(12)	1.356(6)	C(24)–C(25)	1.390(7)
C(1)–C(2)	1.378(9)	C(25)–C(26)	1.375(11)
C(2)–C(3)	1.374(9)	C(26)–C(27)	1.375(10)
C(3)–C(4)	1.376(9)	C(27)–C(28)	1.391(8)
C(4)–C(5)	1.386(7)	C(29)–C(30)	1.371(7)
C(5)–C(6)	1.493(7)	C(29)–C(34)	1.386(7)
C(6)–C(7)	1.483(7)	C(30)–C(31)	1.378(11)
C(7)–C(8)	1.399(8)	C(31)–C(32)	1.349(11)
C(8)–C(9)	1.388(11)	C(32)–C(33)	1.348(10)
		C(33)–C(34)	1.383(8)
C(23)–Sn–C(29)	118.3(2)	O(1)–C(12)–N(4)	122.8(4)
C(17)–Sn–C(29)	116.3(2)	N(4)–C(12)–C(13)	116.1(4)
C(17)–Sn–C(23)	123.9(2)	O(1)–C(12)–C(13)	121.2(4)
O(2)–Sn–C(29)	88.2(2)	S–C(13)–C(12)	117.2(3)
O(2)–Sn–C(23)	83.3(2)	C(12)–C(13)–C(14)	124.9(3)
O(2)–Sn–C(17)	86.7(2)	S–C(13)–C(14)	117.9(3)
Cl–Sn–C(29)	95.7(1)	C(13)–C(14)–C(15)	92.9(3)
Cl–Sn–C(23)	92.5(1)	C(14)–C(15)–C(16)	117.4(5)
Cl–Sn–C(17)	93.9(1)	S–C(16)–C(15)	117.8(5)
Cl–Sn–O(2)	175.3(1)	Sn–C(17)–C(22)	119.6(4)
C(13)–S–C(16)	93.8(3)	Sn–C(17)–C(18)	121.9(4)
C(1)–N(1)–C(5)	117.0(4)	C(18)–C(17)–C(22)	118.3(6)
C(7)–N(2)–C(11)	117.2(5)	C(17)–C(18)–C(19)	121.7(7)
N(4)–N(3)–C(6)	120.8(4)	C(18)–C(19)–C(20)	118.1(9)
N(3)–N(4)–C(12)	117.9(4)	C(19)–C(20)–C(21)	122.0(14)
N(1)–C(1)–C(2)	124.8(5)	C(20)–C(21)–C(22)	120.5(12)
C(1)–C(2)–C(3)	117.5(6)	C(17)–C(22)–C(21)	119.4(7)
C(2)–C(3)–C(4)	119.0(6)	Sn–C(23)–C(28)	120.5(3)
C(3)–C(4)–C(5)	119.7(5)	Sn–C(23)–C(24)	122.1(3)
N(1)–C(5)–C(4)	121.9(4)	C(24)–C(23)–C(28)	117.4(4)
C(4)–C(5)–C(6)	122.2(5)	C(23)–C(24)–C(25)	120.5(5)
N(1)–C(5)–C(6)	115.8(4)	C(24)–C(25)–C(26)	120.4(6)
N(3)–C(6)–C(5)	111.2(4)	C(25)–C(26)–C(27)	120.5(7)
C(5)–C(6)–C(7)	121.7(4)	C(26)–C(27)–C(28)	119.4(6)
N(3)–C(6)–C(7)	127.1(4)	C(23)–C(28)–C(27)	121.8(5)
N(2)–C(7)–C(6)	117.1(5)	Sn–C(29)–C(34)	122.8(4)
C(6)–C(7)–C(8)	120.6(5)	Sn–C(29)–C(30)	120.0(4)
N(2)–C(7)–C(8)	122.2(5)	C(30)–C(29)–C(34)	117.0(5)
C(7)–C(8)–C(9)	117.8(6)	C(29)–C(30)–C(31)	121.4(6)
C(8)–C(9)–C(10)	120.1(8)	C(30)–C(31)–C(32)	120.3(8)
C(9)–C(10)–C(11)	118.6(8)	C(31)–C(32)–C(33)	120.1(7)
N(2)–C(11)–C(10)	124.0(7)	C(32)–C(33)–C(34)	120.1(6)
		C(29)–C(34)–C(33)	121.0(5)

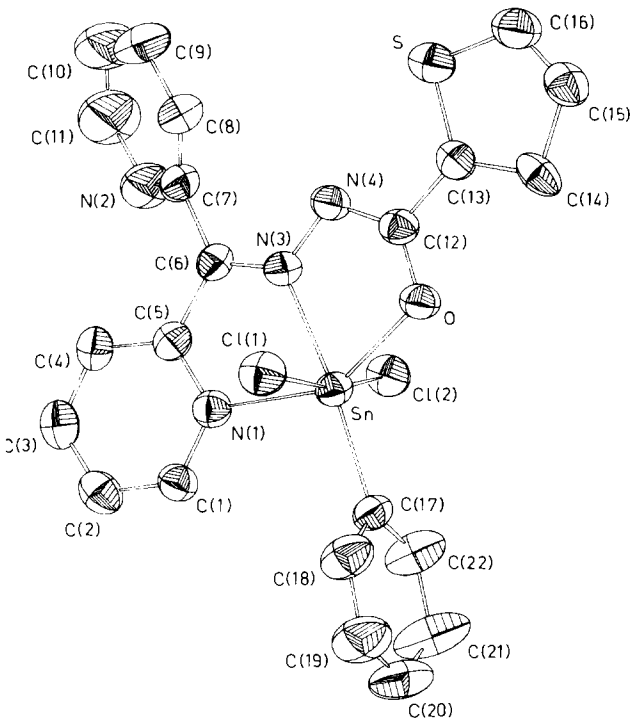

Fig. 1. ORTEP diagram of compound **1**. Thermal ellipsoids are drawn at the 50% probability level.

ported [2]. Concentrations used were as given: Hdpt, 50–100–250–500 μg/plate; **1**, 200–500–1000 μg/plate; **2**, 1–5–25 μg/plate.

3. Results and discussion

3.1. X-ray structures

An ORTEP view of the molecular structures showing the atomic numbering schemes is given in Fig. 1 for **1** and in Figs. 2 and 3 for **2**. In both cases only one of the conformations generating the disorder in the thienyl ring is shown. The most interesting feature of these compounds concerns the behaviour of the hydrazone molecule. In **1** it is deprotonated and behaves as an ONN tridentate donor; in contrast, in **2** it is neutral and does not enter the coordination sphere of the tin atom, this representing a novelty in the chemistry of this class of polyfunctional molecules.

In compound **1** the tin atom is six-coordinate in a highly distorted octahedral shape which involves the three hydrazone atoms, one phenyl carbon, and two *trans* chlorines. The distortions away from ideal octahedral geometry are primarily due to the constraints imposed by the dpt which causes the O(1)–Sn–N(3) and N(1)–Sn–N(3) angles to be 73.5(2)° and 72.1(2)° and the O(1)–Sn–N(1) angle to be 145.6(2)° instead of the ideal 90° and 180°. Even if to a much lesser degree, the other two *trans* angles are also far from linearity,

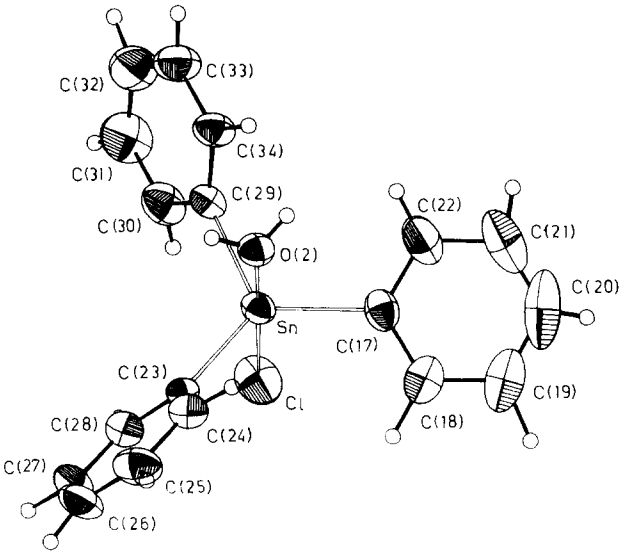

Fig. 2. ORTEP diagram of $[SnPh_3Cl(OH_2)]$ in compound **2**. Thermal ellipsoids are drawn at the 40% probability level.

Cl(1)–Sn–Cl(2) = 166.8(1)° and N(3)–Sn–C(17) = 172.3(2)°. Least squares planes drawn through the set of donor atoms forming the three coordination planes of the octahedron show small deviations from planarity for two of them (max. deviation 0.06 Å for O(1)N(1)N(3)C(17)Sn and 0.20 Å for Cl(1)Cl(2)N(3)C(17)Sn) and a greater deviation for the third (max. deviation 0.49 Å for Cl(1)Cl(2)O(1)N(1)Sn). The coordination of dpt to tin produces two planar five-membered chelate rings which attain a nearly perfect coplanarity. Compound **1** is closely related to $[SnPh(dpa)Cl_2]$ (Hdpa = di-2-pyridylketone 2-aminobenzoylhydrazone) [4] as far as the metal environment and the hydrazone behaviour are concerned. The replacement of dpa by dpt makes the coordination polyhedron slightly more distorted and causes some differences in the bond distances at tin which may be significant. The Sn–N distances in **1** are ca. 0.07 Å longer than those in the dpa derivative,

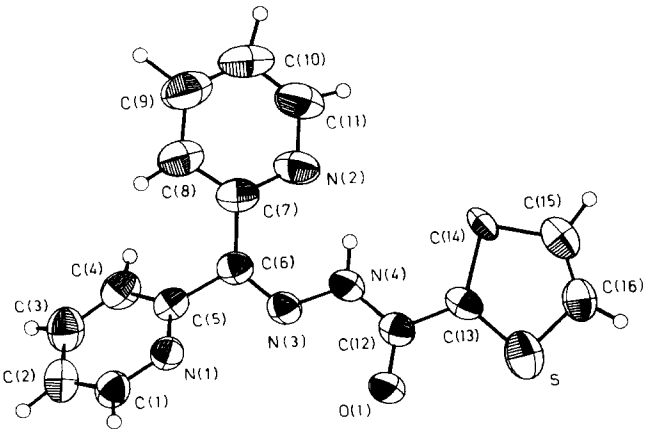

Fig. 3. ORTEP diagram for Hdpt in compound **2**. Thermal ellipsoids are drawn at the 40% probability level.

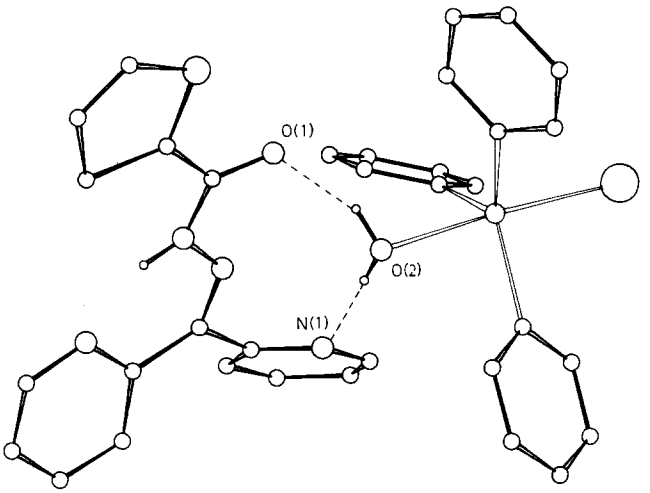

Fig. 4. Molecular association via hydrogen bonding in compound **2**.

while the Sn–O and Sn–C distances are ca. 0.09 and 0.05 Å, respectively, shorter. The two Sn–Cl distances are almost identical in **1**, but differ by a significant 0.03 Å in the dpa compound. The Sn–Cl bonds are typical of mutually *trans* coordinated chlorines in six-coordinate organotin compounds and the Sn–O and Sn–N distances fit well into the ranges observed for tin(IV) hydrazone derivatives, all of which are seven-coordinate [4]. The molecular packing is dominated by van der Waals interactions, the shortest contacts being Cl(2) · · · C(1) $(-x, -y, -z)$ 3.377(6) and C(4) · · · C(14) $(x, y, z-1)$ 3.402(7) Å.

Compound **2** is a 1:1 molecular complex between $[SnPh_3Cl(OH_2)]$ and Hdpt, the association between the component molecules being effected by hydrogen bonding involving the water molecule coordinated to tin, which forms two hydrogen bonds to O(1) and N(1) of the Hdpt in its own asymmetric unit, as shown in Fig. 4. The characteristics of these bonds are: O(2) · · · O(1) 2.746(5) Å; O(2)–H(2) · · · O(1) 158°; O(2) · · · N(1) 2.868(5) Å, O(2)–H(1) · · · N(1) 167°.

In the crystal lattice such pairs of molecules are held together by van der Waals interactions only, the following contacts being the shortest: Cl · · · S $(1/2-x, 1/2+y, 1/2-z)$ 3.456(3); C(15) · · · N(1) $(-x, 1-y, 1-z)$ 3.442(7) Å. A similar molecular association between $[SnPh_3Cl(OH_2)]$ and a polyfunctional compound has been previously observed for 2,2′:6′,2″-terpyridyl [13] and 3-(2-(1,10-phenanthrolyl))-5,6-diphenyl-1,2,4-triazine [14]. As pointed out by Prasad et al. for the terpyridyl adduct, an explanation for such a behaviour can be found in the Lewis acidity of tin, which with three phenyl groups and a chlorine atom attached is not sufficient for two or three atoms of the ligand to be coordinated. In addition, there are steric restraints due to the bulkiness of the hydrazone which make unidentate coordination unfavourable. The tin atom is five-coordinate and has a slightly distorted trigonal bipyramidal environment, where the equatorial positions are occupied by carbon atoms and the apices by the chlorine and the oxygen atom of the water molecule, the *trans* Cl–Sn–O(2) angle being close to the linearity (175.3(1)°). In the trigonal girdle the sum of the valence angles at tin is 358.5°, slightly smaller than the ideal 360°, due to the displacement of tin out of the C_3 plane (0.15 Å, towards Cl) and the deviations of the three angles from the ideal value of 120° are less than 4°. The Sn–C and Sn–Cl distances have normal values, fairly consistent with those reported for related compounds [15], while the Sn–O distance is rather long. This may be accounted for the strong intermolecular hydrogen bonds in which the oxygen atom is involved. Similar long Sn–O bond distances have been found in the two aforementioned hydrogen-bonded tin compounds.

Compared to the conformation assumed by Hdpt in **2**, a rotation around the C(6)–C(7) bond occurs for dpt in **1**, which permits N(2) to be involved in a strong intramolecular hydrogen bond with the adjacent N(4) nitrogen (N(2) · · · N(4) 2.612(7) Å; N(2) · · · H–N(4) 141°). In both compounds the hydrazone is non-planar and can be described in terms of two near-planar parts, the N(2) · · · C(11) pyridine ring and the rest of the molecule, whose atoms are nearly coplanar in **1** (max. deviation 0.06 Å), but show a maximum deviation of 0.28 Å from the least-squares best plane in **2**. The

Table 6
Antimicrobial activity

Compound	MIC (μg/ml)						EC_{50} (μg/ml)				
	BS [a]	SA	EC	SC	CT	AN	BC	FS	PI	SM	SV
$SnPh_2Cl_2$ [b]	3	1.5	3	25	25	12	5	10	2	14	5
$SnPh_3Cl$ [b]	0.3	0.3	> 100	0.7	1.5	0.7	0.5	1	0.1	1	0.5
Hdpt	12	25	> 100	> 100	> 100	> 100	– [c]	–	–	–	–
$SnPh(dpt)Cl_2$ (**1**)	12	25	> 100	> 100	> 100	> 100	–	–	–	–	–
$SnPh_3Cl(OH_2)$ · Hdpt (**2**)	1.5	1.5	> 100	25	12	6	0.5	4	0.3	8	5

[a] BS, *Bacillus subtilis*; SA, *Staphylococcus aureus*; EC, *Escherichia coli*; SC, *Saccharomyces cerevisiae*; CT, *Candida tropicalis*; AN, *Aspergillus niger*; BC, *Botrytis cinerea*; FS, *Fusarium* spp.; PI, *Pythium irregulare*; SM, *Sclerotinia minor*; SV, *Stemphylium vesicarium*. [b] Data previously reported [2]. [c] Not tested.

dihedral angle between the two moieties is 43.8(2)° in **1** and 47.4(1)° in **2**.

3.2. IR spectra

The different behaviour of Hdpt in the two organotin compounds is also evident on comparing the IR vibrational absorptions. The spectroscopic pattern observed for compound **2** is almost similar to that of pure hydrazone consistent with its non-coordination. In contrast, the deprotonated nature and the ONN tridentate ligand behaviour of the hydrazone in compound **1** makes the spectrum of **1** different, the most important changes concerning the disappearance of the ν(NH) and ν(C=O) bands, a consequence of the deprotonation of the NH group and the decrease of double bond character of the C=O group, respectively.

3.3. Biological activity

3.3.1. Antimicrobial activity

The in vitro antimicrobial activity of Hdpt and compounds **1** and **2** is summarized in Table 6. The compounds showed antibacterial activity preferentially against Gram-positive bacteria. Compound **2** proved to have a very strong activity against *Bacillus subtilis* and *Staphylococcus aureus* and also toward several *Bacilli*, with minimum inhibitory concentrations ranging from 1.5 to 3 μg/ml (data not shown).

Compound **2** was the only one effective against the fungi tested; remarkable activity was found against *Aspergillus niger*. Differences in sensitivity were detected among phytopathogenic fungi: *Pythium irregulare* and *Botrytis cinerea* were the most sensitive fungi. In general, parent organotins showed an higher antimicrobial activity as compared with the corresponding complexes. These results are consistent with the hypothesis that complexation by a polyfunctional ligand decreases its biological activity [2]. Accordingly, compound **1** showed the same antimicrobial activity as the Hdpt, while compound **2** exhibited an intermediate potency. Its toxicity can be related to the weak bond between the dpt and triphenyltin chloride.

3.3.2. Genotoxicity

In spite of the presence of chemical groups often associated with genotoxicity, all compounds were devoid of DNA-damaging activity in the *Bacillus subtilis rec*-assay and of mutagenicity in the *Salmonella* test (data not shown). The high antimicrobial activity of compound **2** and the lack of genotoxicity make it attractive and safe for practical use.

Acknowledgments

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