Adducts of Tin(II) Chloride with Imidazole and Methylimidazoles

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Abstract

Reactions of $SnCl_2$ with excess imidazole, 1-methyl-, 4-methyl- and 1,2-dimethylimidazole in THF afforded solid 1:2 adducts in each case. The products were air-sensitive white solids with minimal solubilities in most unreactive solvents. Investigation of the adducts by IR, NMR and X-ray PES indicated that their structures involved coordination of the pyridine-like nitrogen atom of the imidazole ring to the tin atom. Proton and ligand exchange reactions were indicated in DMSO solutions of the adducts.

Introduction

The biological activity of metal complexes of azoles is attracting increased attention to the development of their chemistry [1–3]. The important role played by the imidazole group in enzymes such as chyomotrypsin, creatine kinase and carboxypetidase A, in phosphorylation and its involvement, as a part of histidine, in the binding of oxygen by hemoglobin and myoglobin are of particular interest. Metal complexes of imidazole, benzimidazole and their derivatives have been found to be promising agents for stimulating antitumor and antimicrobial activity [4, 5]. Among the metals forming coordination compounds with imidazole and its derivatives, most are d-block metals [6, 7] and relatively few investigations have involved imidazole coordination to Group 14 metals [8]. The current work describes the synthesis and spectroscopic characterization of $SnCl_2$ adducts with imidazole and methylimidazoles.

Experimental

Materials and Methods

All reactions and manipulations were carried out under flowing dry nitrogen or by using vacuum techniques [9]. Tetrahydrofuran and ethyl ether (Mallinckrodt) were treated to remove peroxides, dried and distilled. Anhydrous tin(II) chloride (Aldrich), dimethyl sulfoxide-d_6 (MSD Isotopes), imidazole (Aldrich), 1-methyl-, 4-methyl- and 1,2-dimethylimidazole (Chemalog) were used as received.

IR spectra were obtained as KBr disks or between NaCl plates. ^1H and ^{13}C NMR spectra were obtained on a GE QE-300 instrument at 300 and 75.5 MHz, respectively; ^{119}Sn spectra were obtained on an IBM AF-80 instrument at 29.88 MHz. Negative δ values correspond to shifts upfield from the reference. All NMR samples were prepared in dimethyl sulfoxide-d_6 solution, dilute for ^1H and approaching saturation for ^{13}C and ^{119}Sn spectra. A Perkin-Elmer PHI Model 550 ESCA/SAM instrument with dual anodes (Mg Kα, 1253.6 eV and Al Kα, 1486 eV) was used to obtain XPS data. Melting ranges were obtained on a MEL-TEMP apparatus using glass capillaries sealed with wax.

Analytical Techniques

Tin (100–200 mg samples) was determined gravimetrically as SnO_2 after precipitation from hot, dilute HNO_3 solution in the presence of NH_4NO_3 followed by heating at 1000–1200 °C to constant mass [10]. The filtrate after precipitation was used for chlorine determination by potentiometric titration with standard silver nitrate solution. C, H and N analyses were carried out by Galbraith Laboratories and Atlantic Microlabs.

Adduct Syntheses

In a typical preparation, 30 mmol (5.69 g) anhydrous $SnCl_2$ was placed in a reaction flask, which was attached to a Schlenk vacuum line where 75 ml of THF was added. After stirring to dissolve the tin(II) chloride, another 75 ml of a THF solution of a slight excess of the imidazole was added with stirring and warming. In the case of imidazole and 1-methylimidazole reactions, the adducts formed precipitates upon cooling; with 4-methylimidazole and 1,2-dimethylimidazole it was necessary to add about 50 ml of ethyl ether which caused the separation of a yellow, oily product. After stirring and removal of solvent, addition of ether was repeated several times until dry solids were obtained. The products, $SnCl_2 \cdot 2$(imida-

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TABLE 1. Binding energy values of $SnCl_2$·imidazole adducts

Sample	E_b (eV)			
	C1 2p	C1s	N1s	$Sn3d_{5/2}$
$SnCl_2$	201.4 (α) 203.4 (β)			489.6
Imidazole		286.4 (4, 5) 287.7 (2)	399.8 (3) 401.4 (1)	
I	200.4 (α) 202.0 (β)	286.9 (4, 5) 288.6 (2)	401.5 (1) 402.9 (3)	488.8
4-Methylimidazole		286.0	399.9 (3) 401.4 (1)	
II	198.8 (α) 201.9 (β)	285.3 287.8	400.1 (1) 402.9 (3)	487.8
III	199.0 (α) 200.4 (β)	285.8 (4, 5, 6) 287.6 (2)	401.4 (1) 402.9 (3)	487.7
IV	201.9 (α) 203.5 (β)	285.6 (4, 5) 288.0 (2, 7) 290.8 (6)	400.6 (1) 403.9 (3)	 488.0

zole) (**I**, 83%, melting point (m.p.) 139–141 °C), $SnCl_2$·2(1-methylimidazole) (**II**, 88%, m.p. 102–103 °C), $SnCl_2$·2(4-methylimidazole) (**III**, 72%, m.p. 83–85 °C) and $SnCl_2$·2(1,2-dimethylimidazole) (**IV**, 63%, m.p. 97–99 °C) were air-sensitive white solids. Analytical data (C, N, H, Sn and Cl) for the four adducts were satisfactory.

Results and Discussion

While adducts of the form $SnX_2 \cdot n$(N-donor) (X = F, Cl, Br, I; n = 1, 2) have been known for some time [11], to our knowledge, none involving imidazole or its methyl derivatives have been reported. The biological activity of imidazoles coupled with the antitumor activity of organotin dihalides [12] have led us to prepare $SnCl_2$·2Im adducts (Im = imidazole, 1-methyl, 4-methyl, and 1,2-dimethylimidazole). Elemental analyses established the 1:2 composition of the adducts.

The potential donor bifunctionality of the imidazole ring raised the question of which nitrogen forms the coordinate bond to tin in the adducts. In known, structurally characterized metal halide–imidazole complexes the pyridine-like nitrogen of imidazole is usually the coordinate bond site [13] in agreement with the results of quantum-chemical calculations [14] indicating the aromatic nature of the ligand and suggesting that the pair of electrons on N-3 is the only accessible unshared pair [6]. However, in some cases, coordination to N-1 has also been claimed [15] so we sought structural information on the new adducts from their XPS, NMR and IR spectra.

Table 1 lists XPS data for the adducts and two of the ligands. Of interest are the shifts in the N1s binding energies resulting from coordination. In our spectrum of imidazole itself a broad N1s peak consisting of two components with binding energies (E_b) of 399.8 and 401.4 eV in intensity ratio of 1:1.5 represented the two nitrogens of the heterocyclic ring. Following the usual principle that higher localized positive charge leads to higher E_b values and recognizing that protonation of the nitrogen atom results in a 1–2 eV increase in E_b [16], we assign the 399.8 and 401.4 eV lines as representing the pyridine (N-3) and pyrrole (N-1) nitrogens of the structure. The XPS spectrum of **I** consisted of two overlapping peaks at 402.9 and 401.5 eV accompanied by a small peak at 399.1 eV. The latter was attributed to a minor amount of uncomplexed ligand remaining in the sample. We assign the signal at 402.9 eV to N-3, which is shifted 3.1 eV toward higher binding energy due to its coordination to the tin in $SnCl_2$. The signal for the pyrrole nitrogen is only slightly increased (0.1 eV) from its value in the free ligand suggesting that it is not the site of coordination and experiences only a small charge perturbation due to coordination of N-3 to tin.

The C1s bands representing C-4 and C-5 were not resolved in our spectra of either imidazole (E_b = 286.4 eV) or in **I** (E_b = 286.9 eV) but were reported resolved in imidazole (C-4 = 285.7, C-5 = 286.5 eV) in another study [17], with which our assignments are in agreement. A signal at the expected higher binding energy was seen for C-2 in imidazole and this shifted toward higher binding energy by almost 1 eV in **I** reflecting a moderate flow of negative charge

TABLE 2. ^{1}H, ^{13}C and ^{119}Sn NMR spectra

Imidazole	I	1-Methylimidazole	II	4-Methylimidazole	III	1,2-Dimethylimidazole	IV
$\delta(^{1}H)$ (ppm)							
11.6 (H-1)	12.0 (H-1)	7.56 (H-2)	7.82 (H-2)	12.08 (H-1)	8.89 (H-1)	7.01 (H-4)	7.06 (H-4)
7.70 (H-2)	7.91 (H-2)	7.08 (H-5)	7.19 (H-5)	7.71 (H-2)	7.76 (H-2)	6.78(H-5)	6.84 (H-5)
7.03 (H-4,5)	7.14 (H-4,5)	6.90 (H-4)	7.03 (H-4)	6.87 (H-5)	6.81 (H-5)	3.54 (CH_3-1)	3.52 (CH_3-1)
		3.62 (CH_3)	3.67 (CH_3)	2.28 (CH_3)	2.11 (CH_3)	2.28 (CH_3-2)	2.28 (CH_3-2)
$\delta(^{13}C)$ (ppm)							
135.4 (C-2)	136.3 (C-2)	138.0 (C-2)	138.2 (C-2)	134.6 (C-2)	135.2 (C-2)	144.2 (C-2)	144.5 (C-2)
		128.6 (C-5)	127.0 (C-5)	131.1 (C-4)	129.7 (C-4)	126.0 (C-4)	124.6 (C-4)
						120.6 (C-5)	120.9 (C-5)
121.8 (C-4,5)	121.5 (C-4,5)	120.6 (C-4)	121.1 (C-4)	118.2 (C-5)	119.0 (C-5)	32.1 (CH_3-1)	32.5 (CH_3-1)
		32.6 (CH_3)	33.5 (CH_3)	11.7 (CH_3)	10.8 (CH_3)	12.3 (CH_3-2)	11.9 (CH_3-2)
$\delta(^{119}Sn)$ (ppm) $SnCl_2$ $\delta(^{119}Sn) = -383.5$ ppm							
−397.6	−327.3	−334.1	−397.6				

away from the coordinated imidazole ring. The decrease in E_b (0.8 eV) for the Sn $3d_{5/2}$ of **I** compared to $SnCl_2$ represents a corresponding increase in negative charge on the acceptor site. A similar decrease occurs in the Cl 2p binding energies. The XPS binding energies of **I** are not consistent with the presence of the imidazole anion where N1s E_b values, for example, are 1 to 2 eV below those of the neutral ligand [17].

The same general relationships exist among the binding energies of 4-methylimidazole and **III** except that the bands for C-4, C-5 and C-6 were not resolved in either case. The close similarity of the Sn $3d_{5/2}$ coordination shifts of **I** and **III** indicates that the magnitude of charge transfer is approximately the same in the two adducts; thus methyl substitution at C-4 does not appear to have a major impact on donor strength here. Since our XPS instrument could not accommodate the other two imidazole ligands (volatility), only the binding energies of their adducts are included in Table 1.

IR Spectra

Our IR spectrum of imidazole is in reasonable agreement with one published earlier [18]. As expected, the presence of coordinated $SnCl_2$ gives rise to new bands in the low frequency region of the spectra of the adducts. The appearance of the N–H stretching absorption near 3120 cm^{-1} and the N–H bending absorption near 1533 cm^{-1} in imidazole and in **I** is consistent with the ligand remaining protonated in **I**. Bands at 1515 and 1530 cm^{-1} in 1-methylimidazole, which lacks the N–H group, are attributable to N–C stretching modes.

The frequencies of the IR bands of imidazole do not shift markedly upon coordination to tin suggesting that the interaction is relatively weak in terms of its influence on the other bonds and groups within the ligand. Ring stretching vibrations appearing in the range of 1420–1440 cm^{-1} in the ligands shift only about 20 cm^{-1}. An intense C–H bending absorption in the range of 1025–1050 cm^{-1} exhibits even smaller coordination shifts. Overall, the spectra are consistent with the weak adduct character of the products but do not provide direct evidence for Sn–N-3 coordination.

NMR Spectra

Although there are four structurally different protons on the imidazole ring, those on C-4 and C-5 are magnetically equivalent [19] so only three resonances are observed (Table 2). In the ^{1}H spectrum of **I** those signals appear shifted downfield by 0.21 (H-2), 0.11 (H-4 and H-5) and 0.4 (H-1) ppm. Very similar behavior is seen in the ^{13}C spectra of imidazole and **I**. In neither case are the signals for C-4 and C-5 resolved and only small coordination shifts are seen. The equivalence of both hydrogens 4 and 5 and

carbons 4 and 5 suggests that rapid H exchange is occurring in solution. Such exchange is favored by the use of DMSO as solvent; it has also been proposed to account for the NMR spectra of d-block metal–imidazole complexes [6]. The equivalences in the spectra of the adducts suggest that two processes, rapid exchange between coordinated and free ligand and, additionally, exchange of the proton between ring nitrogens, are active. Such processes, if present, obviate the question of which nitrogen is coordinated to the tin in DMSO solutions of **I**.

In the case of 1-methylimidazole with no possibility of N–H exchange, all protons give distinguishable resonances. Again, coordination results in small downfield changes in the shifts of **II**. It seems likely that if coordination occurred at N-1, a larger change in the methyl proton shift for adduct **II** than is recorded in Table 2 (0.05 ppm) would ensue. In 4-methylimidazole there is again the opportunity for N–H exchange but the methyl substitution at C-4 removes the opportunity to see its effect in the spectra. The coordination shift of the methyl resonance in **III** is some three times as large as in **II** and in the opposite direction consistent with the coordinate interaction being localized on the neighboring N-3. However, the ^{1}H coordination shifts between 1,2-dimethylimidazole and **IV** are quite small even on the C-2 methyl adjacent to the proposed coordination site. The ^{13}C spectra of the methylimidazoles and their $SnCl_2$ adducts exhibit small coordination shifts comparable to those seen in **I**; those at C-2 are smallest in magnitude and positive while those at C-4 and C-5 are larger and mainly negative in sign. The coordination shifts resemble those reported for imidazole adducts of trialkyltin halides [8a]. They are consistent with relatively weak Sn–N coordinate bonding accompanied by ligand exchange in DMSO solution.

The ^{119}Sn NMR signals of the adducts exhibit coordination shifts from –14 ppm (**I**) to +56 ppm (**II**). These coordination effects are larger than would be expected from solution and temperature variables alone [20, 21], but they do not correlate closely with the pK_a values of the ligands or our intuitive ideas of the order of ligand donor strength towards $SnCl_2$. This result is not surprising in the context of earlier work which found no substantial correlation between ^{119}Sn chemical shifts and solvent donor strength parameters in SnX_2 (X = F, Cl, Br, I) solutions in several solvents [20].

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