

Lead Sequestering Agents. 2. Synthesis of Mono- and Bis(hydroxypyridinethione) Ligands and Their Lead Complexes. Structure of Bis(6-(diethylcarbamoyl)-1-hydroxy-2(1*H*)-pyridine-2-thionato-*O,S*)lead(II)¹

Kamal Abu-Dari,[†] Timothy B. Karpishin, and Kenneth N. Raymond*

Department of Chemistry, University of California, Berkeley, California 94720

Received December 2, 1992

Mono- and bis(hydroxypyridinethione) ligands have been prepared by the reaction of the amines and diamines with the active amide produced from the 2-mercaptopyridine-6-carboxylic acid 1-oxide and 1,1-carbonyldiimidazole in DMF. Compounds thus prepared are 6-(dimethylcarbamoyl)-1-hydroxy-2(1*H*)-pyridine-2-thione, 6-(diethylcarbamoyl)-1-hydroxy-2(1*H*)-pyridine-2-thione, [1,2-ethanediybis(iminocarbonyl)]bis(1-hydroxy-2(1*H*)-pyridine-2-thione), and [1,4-butanediylbis(iminocarbonyl)]bis(1-hydroxy-2(1*H*)-pyridine-2-thione). These ligands and their lead(II) complexes have been characterized by their elemental analyses and IR and NMR spectra. The structure of bis(6-(diethylcarbamoyl)-1-hydroxy-2(1*H*)-pyridine-2-thionato-*O,S*)lead(II) has been determined by single-crystal automated-counter X-ray diffraction. The complex crystallizes in the orthorhombic space group *P*2₁2₁2 with *Z* = 4, *a* = 10.1799(9) Å, *b* = 25.275(4) Å, *c* = 9.6649(11) Å. Full-matrix least-squares refinement using 1712 reflections with $F_o^2 > 3\sigma(F_o)^2$, with all non-hydrogen atoms given anisotropic temperature factors, converged to *R* = 0.025, *R*_w = 0.031. The structure of the complex is based on a five-coordinate geometry in which a sulfur atom, an oxygen atom and the stereochemically active electron lone pair on Pb²⁺ occupy the equatorial positions of a trigonal bipyramid. The axial positions are occupied by sulfur and oxygen atoms. In addition there are weak, outer sphere coordination Pb–O bonds that occur from the ligation by the *N*-hydroxyl and carbonyl oxygen atoms of a neighboring molecule.

Introduction

We began this series of papers with a general description of the toxicity of lead, the steady and enormous growth of the amount of lead released to the environment by human activities, and the current status of lead chelation therapy.¹ It remains the case that no lead-selective sequestering agent has been the result of a rational synthesis. Compounds used for lead chelation therapy were already in the pharmacopoeia for other purposes. Our target is the synthesis of chelating ligands that are powerful, and selective, chelating agents for lead ion. We previously reported the synthesis and structural characterization of lead thiohydroxamate complexes,¹ and we extend this work to include the cyclic thiohydroxamate group, 1-hydroxy-2(1*H*)-pyridinethionato group, since thiohydroxamic acids form particularly stable complexes with lead ion, as indicated by the high stability constant of lead thiohydroxamate complexes ($\log \beta_2 = 20.7$ for *N*-phenylbenzothiohydroxamic acid in 70% aqueous dioxane)² compared with that of the lead EDTA complex ($\log \beta_1 = 16.5$).³ This relative stability differs markedly from the "harder" metal ions (Cu²⁺, Zn²⁺, Ca²⁺) of principal concern as essential trace elements.

We report here the synthesis of several ligands containing one or two hydroxypyridinethione ligating groups as well as their lead complexes. We also report the X-ray structural characterization of bis(6-(diethylcarbamoyl)-1-hydroxy-2(1*H*)-pyridine-2-thionato-*O,S*)lead(II).

Experimental Section

Lead nitrate (Fisher Scientific Co.) was used for the synthesis of the lead complexes. Dimethyl formamide was dried over alumina and distilled over molecular sieves. Dimethylamine and diethylamine (Matheson

and ethylenediamine, 1,4-diaminobutane, and 1,1-carbonyldiimidazole (Aldrich) were used without further purification; 2-mercaptopyridine-6-carboxylic acid 1-oxide, 4, was prepared as described earlier.⁴ Lab grade solvents and reagents were used throughout the synthesis without further purification. NMR spectra were collected on a custom-built 200-MHz FT spectrometer. Visible–UV spectra were recorded on a Hewlett-Packard 8450A UV–vis spectrometer and IR spectra on a Nicolet 1st instrument. A Kratos MS-50 mass spectrometer using a xenon beam was used to acquire *FAB mass spectra. Melting points were taken in open capillaries with a Buchi apparatus and are uncorrected. Elemental analyses were performed by the Analytical Laboratory, University of California, Berkeley, CA.

Ligand Syntheses (Scheme I). **6-(Dimethylcarbamoyl)-1-hydroxy-2(1*H*)-pyridine-2-thione (2).** A solution of 1,1-carbonyldiimidazole (1.62 g, 10.0 mmol) in DMF (20 mL) was added to a solution of compound 1 (1.71 g, 10.0 mmol) in 20 mL of DMF under N₂. The color of the solution of 1 changed immediately from yellow to wine red with the evolution of carbon dioxide. The solution was stirred under N₂ for 15 min and then saturated with dimethylamine. The color changed immediately to yellowish green. The solution was stirred overnight under N₂. Most DMF was evaporated under reduced pressure, and 100 mL of water was added, resulting in a clear solution. HCl (~3M) was carefully added to pH 1–2, and the solution was extracted with chloroform (300 mL × 3). The chloroform was evaporated under reduced pressure and the viscous liquid product was dried under vacuum at 60 °C. Yield: 1.9 g (96%). FAB: 199 (MH⁺), 183, 167, 154. Anal. Calcd (found) for C₈H₁₀N₂O₂S: C, 48.47 (48.58); H, 5.08 (4.99); N, 14.13 (13.75); S, 16.17 (15.76).

6-(Diethylcarbamoyl)-1-hydroxy-2(1*H*)-pyridine-2-thione (3). This compound was prepared using the same method used for the synthesis of compound 2, using diethylamine instead of dimethylamine. The product was a viscous liquid; yield ~96%. FAB: 227 (MH⁺), 211, 195. Anal. Calcd (found) for C₁₀H₁₄N₂O₂S: C, 53.08 (52.31); H, 6.24 (6.14); N, 12.38 (12.44); S, 14.17 (14.02).

[1,2-Ethanediybis(iminocarbonyl)]bis(1-hydroxy-2(1*H*)-pyridine-2-thione) (4). Compound 1 (2.05 g, 12.0 mmol) was dissolved in 20 mL of DMF. A solution of 1,1-carbonyldiimidazole (1.95 g, 12.0 mmol) in 20 mL of DMF was added under N₂. The resulting red solution was stirred for 15 min, and a solution of ethylenediamine (0.36 g, 6.0 mmol)

* To whom correspondence should be addressed.

[†] On sabbatical leave from the Chemistry Department, University of Jordan, Amman, Jordan.

(1) Previous paper in this series: Abu-Dari, K.; Hahn, F. E.; Raymond, K. N. *J. Am. Chem. Soc.* **1990**, *112*, 1519–1524.

(2) Dietzel, R.; Thomas, P. Z. *Anorg. Allg. Chem.* **1971**, *381*, 214.

(3) Oyama, N.; Matsuda, H.; Ohtaki, H. *Bull. Chem. Soc. Jpn.* **1977**, *50*, 7406.

(4) Abu-Dari, K.; Raymond, K. N. *Inorg. Chem.* **1991**, *30*, 519–524.

in 20 mL of DMF was added, after which the color changed gradually from red to light green. The reaction mixture was stirred under N_2 overnight, after which most of the DMF was evaporated under reduced pressure. Water (100 mL) was added and the mixture was acidified with HCl to pH = 1–2. The product was dissolved in 1 M NaOH solution, and the solution was filtered and acidified with dilute HCl solution. The yellowish precipitate was filtered, washed with water, and dried in vacuum over P_2O_5 . Yield: 1.54 g (70%). Mp: 180–182 °C dec. FAB, 367 (MH⁺), 351, 349, 333. Anal. Calcd (found) for $C_{14}H_{14}N_4O_4S_2$: C, 45.89 (45.96); H, 3.85 (3.74); N, 15.29 (15.18); S, 17.50 (17.52).

[1,4-Butanediybis(iminocarbonyl)]bis(1-hydroxy-2(1H)-pyridine-2-thione (5). Compound 1 (1.026 g, 6.0 mmol) was dissolved in 10 mL of DMF. A solution of 1,1-carbonyldiimidazole (0.973 g, 6.0 mmol) in 10 mL of DMF was added under N_2 . The resulting red solution was stirred for 15 min, and a solution of 1,4-diaminobutane (0.264 g, 3.0 mmol) in 10 mL of DMF was added, after which the color changed gradually from red to light green. The reaction mixture was stirred under N_2 overnight, after which most DMF was evaporated under reduced pressure. Water (100 mL) was added and the mixture was acidified with HCl to pH = 1–2. The yellowish-green precipitate was filtered, washed with water and dissolved in 1 M NaOH solution. The resultant solution was filtered and acidified with dilute HCl solution. The precipitate was removed by filtration, washed with water, and dried in vacuum over P_2O_5 . Yield: 0.85 g (72%). Mp: 189–190 °C dec. FAB, 395 (+MH), 379, 377, 371, 361. Anal. Calcd (found) for $C_{16}H_{18}N_4O_4S_2$: C, 48.72 (48.83); H, 4.60 (4.65); N, 14.20 (14.21); S, 16.26 (15.99).

Syntheses of Lead Complexes. Bis(6-(dimethylcarbamoyl)-1-hydroxy-2(1H)-pyridine-2-thionato-O,S)lead(II) (6). Compound 2 (0.40 g, 2.02 mmol) was dissolved in 50 mL of water, and an equivalent amount of NaOH (20.2 mL, 0.10 M NaOH) was added. To this was added a solution of lead nitrate (0.335 g, 1.01 mmol) in water (20 mL). The resultant yellowish solution was stirred for 30 min, and then water was removed under reduced pressure. The pale yellow residue was extracted into chloroform, the solution was filtered, and chloroform was evaporated under reduced pressure. The product was recrystallized from ethanol-chloroform by slow evaporation. Yield: 0.55 g (90%). Mp: 240–246 °C dec. Anal. Calcd (found) for $Pb(C_8H_9N_2O_2S)_2$: C, 31.94 (32.00); H, 3.02 (2.97); N, 9.31 (9.29).

Bis(6-(diethylcarbamoyl)-1-hydroxy-2(1H)-pyridine-2-thionato-O,S)-lead(II) (7). Compound 3 (0.45 g, 2.0 mmol) was dissolved in 50 mL of water, and equivalent amount of NaOH solution (20.0 mL, 0.10 M) was added. To this solution was added a solution of lead nitrate (0.331 g, 1.0 mmol) in water (20 mL). The mixture was stirred for 30 min, and then water was evaporated under reduced pressure. The yellow residue was extracted into chloroform and was recrystallized from chloroform/ethanol by slow evaporation. Yield: 0.59 (90%). Anal. Calcd (found) for $Pb(C_{10}H_{13}N_2O_2S)_2$: C, 36.52 (36.54); H, 3.98 (4.09); N, 8.52 (8.51).

[1,2-Ethanediybis(iminocarbonyl)]bis(1-hydroxy-2(1H)-pyridine-2-thionato-O,S)lead(II) (8). Compound 4 (0.22 g, 0.60 mmol) was dissolved in 12.0 mL of a 0.10 M NaOH solution. The solution was filtered, and to the well-stirred filtrate was added a solution of lead nitrate (0.199 g, 0.60 mmol) in 20 mL of water. The resultant mixture was stirred for 1.0 h, and the yellow precipitate was removed, washed with water, and dried in vacuum over P_2O_5 . Yield: 0.28 g (82%). Mp: 230–240 °C dec. Anal. Calcd (found) for $Pb(C_{14}H_{12}N_4O_4S_2)$: C, 29.42 (28.29); H, 2.12 (1.16); N, 9.80 (9.66).

[1,4-Butanediybis(iminocarbonyl)]bis(1-hydroxy-2(1H)-pyridine-2-thionato-O,S)lead(II) (9). Compound 5 (0.197 g, 0.50 mmol) was dissolved in 10.0 mL of a 0.10 M NaOH solution. The solution was filtered, and to the well-stirred filtrate was added a solution of lead nitrate (0.166 g, 0.50 mmol) in 20 mL of water. The resulting mixture was stirred for 1.0 h, and the yellow precipitate was removed, washed with water, and dried in vacuum over P_2O_5 . Yield: 0.25 g (83%). Mp: 260–270 °C. Anal. Calcd (found) for $Pb(C_{16}H_{16}N_4O_4S_2)$: C, 32.05 (32.23); H, 2.69 (2.71); N, 9.34 (9.25).

X-ray Crystallography

Single crystals of compound 7 were obtained from a chloroform-ethanol solution by slow evaporation. The space group ($P2_12_12$) and preliminary cell dimensions were obtained from precession photography. A single crystal was cleaved in half before mounting on an Enraf-Nonius CAD-4 diffractometer since precession photographs indicated twinning. Final cell parameters were obtained by least-squares refinement of the angular settings of 24 strong reflections in the 2θ range $24.7 \leq 2\theta \leq 27.2^\circ$. Applying θ - 2θ scan techniques and Mo K α radiation, 1885 intensity

Table I. Crystal Data and Intensity Collection

empirical formula	PbC ₂₀ H ₂₆ O ₄ N ₄ S ₂
fw	657.77
cryst dims, mm	0.19 × 0.21 × 0.30
cell params	
<i>a</i> , Å	10.1799(9)
<i>b</i> , Å	25.275(4)
<i>c</i> , Å	9.6649(11)
<i>V</i> , Å ³	2486.7(5)
space group	$P2_12_12$ (No. 18)
<i>Z</i>	4
<i>d</i> _{calcd} , g/cm ³	1.76
<i>d</i> _{obsd} , g/cm ³	1.78 ^a
μ (Mo K α), cm ⁻¹	70.19
radiation	Mo K α (λ = 0.710 69 Å)
reflcs measd	+ <i>h</i> , + <i>k</i> , + <i>l</i>
scan speed, deg/min	0.80–6.67
scan method	θ - 2θ
2θ limits, deg	3.0–45.0
no. of unique data	1885
no. of data with (F_o) ² > 3 σ (F_o) ²	1712
no. of variables	280
<i>R</i>	0.025
<i>R</i> _w	0.031
goodness of fit	1.67

^a Measured by flotation in bromoform/toluene mixture.

data (+*h*, +*k*, +*l*) were collected at 25 °C.⁵ Cell parameters and other crystallographic data are summarized in Table I.

The raw intensity data were converted into structure factor amplitudes and their esd's by correction for scan speed, background, and Lorentz and polarization effects.⁶ Inspection of the list of intensity standards showed a 13.5% decomposition, and hence a decay correction was applied. An absorption correction was made by the use of Ψ -scan data.⁷ The correction factors ranged from 1.00 to 1.20, with an average of 1.05. The structure was solved by standard heavy-atom procedures and refined by full-matrix least-squares methods. A difference Fourier map calculated following anisotropic refinement of all non-hydrogen atoms revealed the position of all hydrogen atoms. The aromatic hydrogens were introduced at fixed positions (C–H distance = 0.95 Å; H–C–H angle = 109.5°). Full-matrix least-squares refinement with 280 variables, using the 1712 reflections with (F_o)² > 3 σ (F_o)², led to convergence with *R* = 0.025 and *R*_w = 0.031. The positional and thermal parameters are listed in Table II.⁸

Results and Discussion

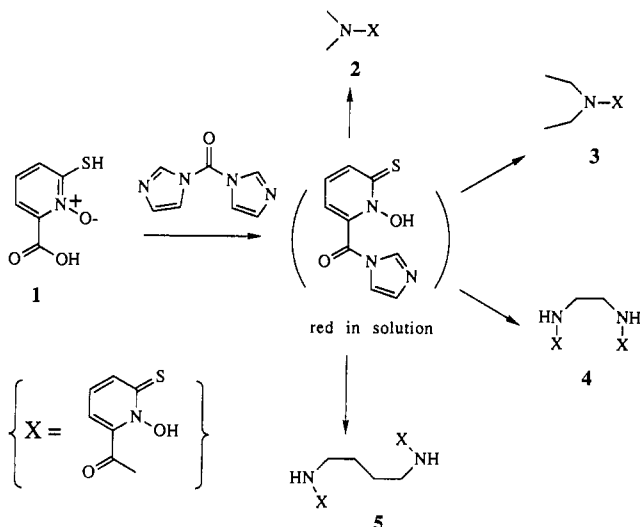
Mono- and diamides of 1-hydroxy-2(1H)-pyridine-2-thione were obtained by the reaction of 2-mercaptopyridine-6-carboxylic acid 1-oxide with 1,1-carbonyldiimidazole in dry DMF to produce the active amide intermediate, which reacts with primary and secondary amines to form the corresponding amides (Scheme 1). The yield per amide bond is usually above 97%, which is higher than the yield obtained for the pyridinone analog using phosgene in THF.⁹ Furthermore, unreacted amines, other reaction products such as imidazole, and unreacted acid (1) are all soluble in dilute HCl solution, which enables the isolation of the amides in pure form. The isolated mono and diamides are pale yellow to greenish in color and are very soluble in DMF and chloroform; the monoamides 2 and 3 are water soluble, while the diamides 4 and 5 are less soluble in aqueous solution. All four compounds are

- (5) The intensities of the three standard reflections (2,3,6), (6,2,1), (2,1,3,–3) were measured every 1 h of X-ray exposure time. Orientation checks of the same three reflections were performed after every 200 intensity measurements. Reorientation was necessary once during data collection.
- (6) For reference to data reduction and processing, see: Eigenbrot, C. W., Jr.; Raymond, K. N. *Inorg. Chem.* **1982**, *21*, 2653.
- (7) Reflections used for the azimuthal (Ψ) scans were located near $\chi = 90^\circ$, and the intensities were measured at 10° increments of rotation of the crystal about the diffraction vector.
- (8) See statement at the end of the article regarding supplementary material.
- (9) White, D. L.; Durbin, P. W.; Jeung, N.; Raymond, K. N. *J. Med. Chem.* **1988**, *31*, 11.

Table II. Positional Parameters and Their Estimated Standard Deviations

atom	x	y	z	$B, \text{\AA}^2$
PB	0.12025(3)	0.06464(1)	0.16787(4)	3.660(6)
S1	0.1144(3)	0.1604(1)	0.2898(3)	5.35(6)
S2	-0.0831(3)	0.0893(1)	-0.0029(3)	4.84(6)
O1	0.2457(7)	0.1256(2)	0.0274(7)	4.6(1)
O2	-0.0855(6)	0.0464(2)	0.2811(6)	3.7(1)
O3	0.5006(8)	0.1616(3)	-0.1577(7)	6.6(2)
O4	-0.2813(8)	-0.0287(3)	0.4288(7)	5.8(2)
N1	0.2627(8)	0.1764(3)	0.0613(8)	4.0(2)
N2	0.3018(9)	0.1740(4)	-0.2633(9)	5.9(2)
N3	-0.2019(7)	0.0626(3)	0.2344(7)	3.2(1)
N4	-0.259(1)	0.0425(4)	0.5652(9)	6.1(2)
C1	0.2086(9)	0.1973(3)	0.180(1)	3.9(2)
C2	0.236(1)	0.2509(4)	0.207(1)	5.7(3)
C3	0.314(1)	0.2797(5)	0.120(1)	6.9(3)
C4	0.364(1)	0.2578(4)	0.001(1)	5.4(2)
C5	0.3351(0)	0.2054(4)	-0.029(1)	4.4(2)
C6	0.3883(9)	0.1768(4)	-0.1560(9)	4.6(2)
C7	0.353(1)	0.1474(6)	-0.391(1)	7.6(3)
C8	0.421(1)	0.185(6)	-0.485(1)	8.4(4)
C9	0.170(1)	0.1944(8)	-0.259(1)	10.2(5)
C10	0.152(2)	0.2475(9)	-0.314(2)	15.2(5)
C11	-0.2153(9)	0.0841(4)	0.105(1)	4.1(2)
C12	-0.344(1)	0.1007(4)	0.065(1)	5.8(3)
C13	-0.446(1)	0.0914(5)	0.152(1)	6.4(3)
C14	-0.431(1)	0.0671(4)	0.278(1)	5.5(3)
C15	-0.3074(9)	0.0532(4)	0.319(1)	4.5(2)
C16	-0.279(1)	0.0196(3)	0.4447(9)	4.4(2)
C17	-0.228(2)	0.0075(6)	0.684(1)	10.8(4)
C18	-0.342(3)	-0.007(1)	0.767(2)	22(1)
C19	-0.258(1)	0.1005(5)	0.584(1)	7.2(3)
C20	-0.121(2)	0.1217(6)	0.582(1)	8.6(4)

^a The thermal parameter given for anisotropically refined atoms is the isotropic equivalent thermal parameter defined as: $(4/3)[a^2B(1,1) + b^2B(2,2) + c^2B(3,3) + ab(\cos \gamma)B(1,2) + ac(\cos \beta)B(1,3) + bc(\cos \alpha)B(2,3)]$ where a , b , and c are real cell parameters and $B(i,j)$ are anisotropic betas.

Scheme I

soluble in neutral or slightly basic ($\text{pH} \geq 6$) aqueous solution. All reported amides exist in the thione form, as indicated by the absence of the S-H stretching frequency in the IR spectra of these compounds in the region $1700\text{--}2900\text{ cm}^{-1}$. In addition to the strong amide C=O stretching frequency in the region $1600\text{--}1700\text{ cm}^{-1}$, there are four bands in the region $1600\text{--}1435\text{ cm}^{-1}$ in the IR spectra of the amide ligands corresponding to the C=N and C=C ring stretching frequencies. These bands appear in the same region in the IR spectrum of 1-hydroxy-2-(1H)-pyridine-2-thione.¹⁰ The most distinct feature in the NMR spectra of

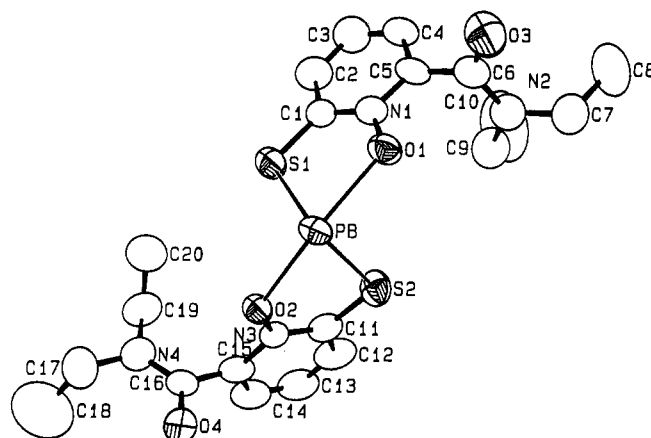


Figure 1. ORTEP view of the lead complex 7 which shows the atom numbering scheme and the general coordination geometry as viewed approximately along the coordination direction occupied by the lone electron pair of Pb^{2+} .

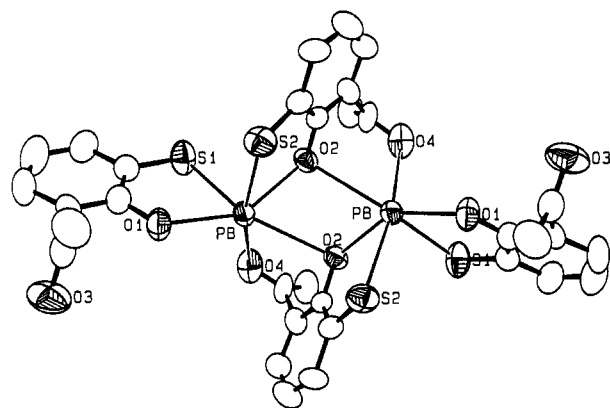


Figure 2. View of the weak dimer of the PbL_2 complex 7 as viewed down the crystallographic and molecular 2-fold axis.

compounds 2–5 is the presence of two doublets at $\delta 6.7\text{--}7.0$ and $\delta 7.5\text{--}7.7$ and a triplet at $\delta 7.3\text{--}7.5$ corresponding to the three 1-hydroxy-2-(1H)-pyridine-2-thione ring hydrogens at positions 3, 5, and 4 respectively. The two doublets are further split into two doublets due to coupling between the 3 and 5 ring protons.

Lead complexes of compounds 2–5 have been prepared by the reaction of lead nitrate with the sodium salt of the ligands. Bis(chelate)lead(II) complexes were obtained in each case; for ligands 2 and 3, these are 1:2 complexes while with ligands 4 and 5 these are 1:1 ligand to metal complexes. All four lead complexes are soluble in organic solvents such as DMSO and chloroform, and 6 is partially soluble in water as well. The IR spectra of the lead complexes are similar in general to those of the uncoordinated ligands, with shifts in the position of some bands. The amide C=O stretching frequency is shifted by about 10 cm^{-1} toward higher frequency. The C=N and C=C ring stretching frequencies at about 1603 , 1576 , 1489 , and 1436 cm^{-1} in the IR spectrum of compound 2 are shifted to 1600 , 1585 , 1478 , and 1425 cm^{-1} , respectively. The NMR spectra of the lead complexes resemble those of the uncoordinated ligands. The signals corresponding to the ring hydrogens are shifted upfield in the lead complexes. For example, the two doublets and the triplet corresponding to hydrogens 3, 5, and 4 respectively appear at $\delta 6.94$, $\delta 7.59$, and $\delta 7.48$ respectively in the NMR spectrum of compound 3 and are shifted upfield to $\delta 6.87$, $\delta 7.48$, and $\delta 7.21$ in the lead complex 7, both spectra recorded in DMS solution.

X-ray Crystallography

Compound 7 is essentially monomeric in the solid state, with a minimum Pb–Pb distance of 4.08 \AA . However the lead ion is weakly complexed by the nitrosyl (O_2) and amide carbonyl oxygen

Table III. Selected Bond Distances (Å) and Angles (deg)^a

Intramolecular Distances			
Pb-S1	2.696(3)	Pb-O4m	3.143(7)
Pb-S2	2.720(3)	S1-C1	1.709(9)
Pb-O1	2.419(6)	S2-C11	1.708(10)
Pb-O2	2.407(6)	O1-N1	1.338(9)
Pb-O2'	3.036(6)	O2-N3	1.331(9)
Intramolecular Angles			
S1-Pb-S2	92.43(9)	S2-Pb-O1	85.06(17)
S1-Pb-O1	71.59(16)	S2-Pb-O2	70.05(15)
S1-Pb-O2	87.37(15)	O1-Pb-O2	146.76(21)

^a The primed atom labels indicate bridging ligands, see Figure 3.

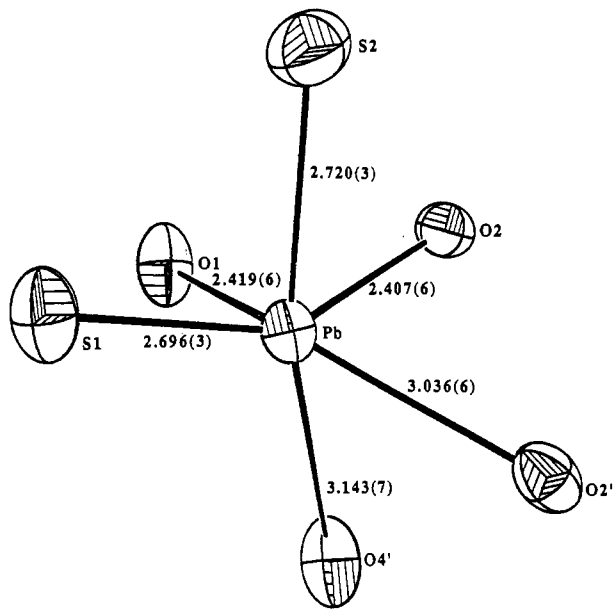


Figure 3. View of the Pb²⁺ coordination in **7**. Both the inner coordination and weak outer coordination due to dimer formation (distinguished by longer Pb-L bond distances) are shown.

(O₄) of a neighboring molecule, resulting in a weakly linked dimer. Figure 1 shows a perspective view of compound **7** with the numbering scheme. Figure 2 is drawn looking down the two-fold axis that relates the two lead complexes in the unit cell. An ORTEP view that shows the Pb²⁺ coordination with the inner and outer sphere ligands and bond distances is shown in Figure 3. Table III gives selected bond lengths, bond angles and dihedral angles for compound **7**. Bond distances and angles within the 1-hydroxy-2(1H)-pyridine-2-thione ring are in general similar to those observed for other 1-hydroxy-2(1H)-pyridine-2-thione complexes.^{4,11,12} Two Pb-S bond distances are observed for compound **7**; the shorter axial Pb-S₁ bond is 2.696 Å, and the

slightly longer equatorial Pb-S₂ bond is 2.720 Å. Similarly two Pb-O bond distances are observed; the shorter axial Pb-O₂ bond is 2.407 Å, and the slightly longer equatorial Pb-O₁ bond is 2.419 Å. Similar results were previously observed for bis(*N*-methylacetohydroxamato)lead(II),¹ but with a larger difference in bond length between the axial and equatorial bonds. Both the Pb-S bond distances in compound **7** are slightly shorter than the Pb-S bond distance (2.746 Å) in bis(*N*-methylthiobenzohydroxamato)lead(II) and the short Pb-S bond distance (2.744 Å) in bis(*N*-methylacetothiohydroxamato)lead(II).¹³ The Pb-S bond distances in compound **7** are comparable to the relatively long Pb-S bond distances (2.55–2.72 Å) reported for lead complexes of mercaptan-containing ligands^{14–18} (where the sulfur donor atom carries a full negative formal charge), and are shorter than the Pb-S bond distances reported for bis(*O,O*-diisopropylphosphodithionato)lead(II)¹⁹ (2.76, 2.77 Å), bis(ethyl xanthinato)lead(II)²⁰ (2.79 Å) and bis(*N,N*-dimethyldithiocarbamato)lead(II)²¹ (2.799, 2.873 Å). The two Pb-O bond distances in compound **7** are longer than the Pb-O bond distance 2.383 Å in bis(*N*-methylthiobenzohydroxamato)lead(II) and the short Pb-O bond distance 2.371 Å bis(*N*-methylthiobenzohydroxamato)lead(II),¹ and are shorter than the Pb-O bond distance of 2.44 Å reported for bis(*D*-pencillaminato)lead(II).¹⁸ These results indicate that the 1-hydroxy-2(1H)-pyridine-2-thione ligand is essentially in the thiol rather than the thione form when coordinated to lead ion. The upfield shift of the NMR of ring protons upon chelation of the ligand to lead ion is also explained by the increase in contribution of the thiol form upon complexation.

Acknowledgment. We thank Ms. Linda Uhlir and Ms. Mary Neu for assistance with the NMR spectra. Some preliminary support of this research via a Biomedical Research Grant from the NIH is acknowledged.

Supplementary Material Available: Listings of root-mean-square amplitudes of vibration and general temperature factor expressions (β 's) (Tables S₁ and S₂) (2 pages). Ordering information is given on any current masthead page.

- (11) Barnett, B. L.; Kretchmar, H. C.; Hartman, F. A. *Inorg. Chem.* **1977**, *16*, 1834.
- (12) Castellato, U.; Vigato, P. A.; Tamburini, S.; Graziani, R.; Vidali, M. *Inorg. Chim. Acta* **1983**, *72*, 141.
- (13) Ibels, L. S.; Pollock, C. A. *Med. Toxicol.* **1986**, *1*, 367–410.
- (14) Dean, P. A. W.; Vittal, J. J.; Payne, N. C. *Inorg. Chem.* **1985**, *224*, 3594.
- (15) Hitchcock, P. B.; Lappert, M. F.; Samways, B. J.; Weinberg, E. L. *J. Chem. Soc., Chem. Commun.* **1983**, 1492.
- (16) Dean, P. A. W.; Vittal, J. J.; Payne, N. C. *Inorg. Chem.* **1984**, *23*, 4232.
- (17) Dance, I. G.; Guernsey, P. J. *Aust. J. Chem.* **1981**, *34*, 57.
- (18) Freeman, H. C.; Stevens, G. N.; Taylor, I. F., Jr. *J. Chem. Soc., Chem. Commun.* **1974**, 366.
- (19) Lawton, S. L.; Kokotailo, G. T. *Inorg. Chem.* **1972**, *11*, 363.
- (20) Hagihara, H.; Yamashita, S. *Acta Crystallogr.* **1966**, *21*, 350.
- (21) Iwasaki, H. *Acta Crystallogr.* **1980**, *B36*, 2138.