Crystal Structure of (DL-Methioninato)methylmercury(II)

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The synthesis of (DL-methioninato)methylmercury(II) from methylmercury hydroxide and DL-methionine is described. Crystals of the title compound are monoclinic, space group $P2_1/c$, with $a = 7.048(9)$, $b = 5.826(4)$, $c = 25.323(53)$ Å, $\beta = 93.2(2)°$, $Z = 4$. The structure was solved by the heavy-atom method by use of 1 027 observed diffractometer-measured reflections and refined to R 0.099. The amino-acid is bound to the methylmercury moiety *via* the amino-group. Important metal–ligand distances are: Hg–N 2.06(4) and Hg–C(6) 2.11(5) Å. Two additional weak interactions to carboxylate oxygen atoms are present. The vibrational spectra and n.m.r. spectra are discussed in the light of the solid-state structure and previous deductions concerning the interaction of methionine with inorganic and organo-mercury compounds.

METHIONINE is an essential sulphur-containing amino-acid, with the sulphur present as a thioether group. The daily requirement is rather high, the rate of uptake by the brain being particularly notable.[1] Demethylation of methionine produces homocysteine $HS{\cdot}[CH_2]_2{\cdot}CH(NH_2)CO_2H$, and is responsible for transmethylation in biological systems. Cysteine is also a metabolite of methionine. The inter-relationship of methionine, cysteine, and homocysteine, as well as the implication of L-cysteine complexes of Hg^{2+} and $MeHg^+$ in mercury poisoning [2] and the involvement of homocysteine complexes in one mechanism for environmental methylation of mercury,[3] suggests that some significance may be attached to methionine–mercury complexes. Considerable recent effort has been expended to establish preferential binding sites in solution.[4-6] From ^1H n.m.r. measurements, binding of $MeHg^+$ is localised at the amino-site at pH 7—9 but at pH *ca.* 2 there is strong evidence for attachment of methylmercury to the thioether sulphur atom.[5,6] We are isolating crystalline methylmercury–methionine complexes for spectroscopic and structural studies in order to establish firm diagnostic criteria for a comparison of bonding modes in solution and in the solid state. For corresponding mercury(II)–methionine complexes there is sound structural evidence for mercury–sulphur and mercury–carboxylate binding in $[Hg\{MeS{\cdot}[CH_2]_2{\cdot}CH(NH_3){\cdot}CO_2\}_2][ClO_4]_2{\cdot}2H_2O$,[7] while for bis(methioninato)mercury, i.r. and Raman spectroscopy indicate N and O bonding of methionine in the solid state [8] and n.m.r. data are consistent with exclusive binding at the thioether site in acid solution.[5] We describe herein the *X*-ray crystal structure of MeHg(met) {met = DL-methioninato, $MeS{\cdot}[CH_2]_2{\cdot}CH(NH_2)CO_2^-$}.

EXPERIMENTAL

Reagents.—Methylmercury hydroxide (Research Organic/Inorganic Chemical Corporation); DL-methionine (Sigma Chemicals); other reagents and solvents, standard reagent-grade chemicals.

Preparation.—Methylmercury hydroxide (0.50 g, 2.16 mmol) and the stoicheiometric quantity of DL-methionine necessary for formation of a 1 : 1 complex were mixed in 50% aqueous ethanol (200 ml) and stirred for several hours. A small amount of precipitate formed, was filtered off, and colourless plate-like crystals were grown from the clear filtrate (Found: C, 19.85; N, 3.85; H, 3.75. $C_6H_{13}HgNO_2S$ requires C, 19.79; N, 3.85; H, 3.57).

Physical Measurements.—I.r. spectra (Nujol mulls) were measured by use of CsI windows on a Perkin-Elmer 180 spectrometer. Raman spectra of solids were obtained on a Jarrel–Ash 25-100 spectrometer with argon-ion laser excitation. The rotating-cell technique was employed to minimise decomposition in the laser beam. ^1H and ^{13}C n.m.r. spectra were measured on Varian T60 and Bruker HFX 90 spectrometers.

Crystal Data.—$C_6H_{13}HgNO_2S$, $M = 363.8$, Monoclinic, $a = 7.048(9)$, $b = 5.826(4)$, $c = 25.323(53)$ Å, $\beta = 93.2(2)°$, $U = 1\,038.3$ Å^3, $D_m = 2.38$ g cm^{-3}, $Z = 4$, $D_c = 2.33$ g cm^{-3}, $F(000) = 672$. Mo-K_α radiation, $\lambda = 0.7107$ Å; μ(Mo-K_α) $= 152.9$ cm^{-1}. Systematic absences: $0k0$, $k = 2n + 1$ and $h0l$, $l = 2n + 1$, space group $P2_1/c$.

Cell constants and space group were determined from *X*-ray photographs and the former refined by least-squares methods based on 2θ values for 15 reflections measured on an XRD 6 diffractometer. The intensities of 3 014 reflections [2θ(Mo-K_α) $\leqslant 60°$] were measured for a crystal of dimensions $0.17 \times 0.15 \times 0.13$ mm. The stationary-crystal–stationary-counter method of data collection was used and the *X*-ray beam was shut off other than during counting time to minimise rapid deterioration of the crystal. The intensities of 3 standard reflections, measured after every 100 reflections, decreased by *ca.* 20% during data collection and were used to scale the data to a common level. Of 3 014 reflections measured, 1 027 having intensities $I \geqslant 3\sigma(I)$ were considered observed and used in the analysis. A background curve was derived by measurements in the interest range of 2θ with ω and ϕ settings non-coincident with those of measured reflections. A cylindrical absorption correction (mean r 0.07 mm) [9] was applied.

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Lorentz and polarisation corrections were applied to the derivation of structure-factor amplitudes.

Structure Analysis.—The structure was solved by the heavy-atom method and refined by full-matrix least-squares procedures, initially with isotropic (R 0.13) and finally with anisotropic thermal parameters {in the form $\exp[-(h^2\beta_{11} + k^2\beta_{22} + l^2\beta_{33} + 2hk\beta_{12} + 2hl\beta_{13} + 2kl\beta_{23})]$}. An empirical weighting scheme of the form $w = (20.0 - 0.2300|F_o| + 0.0030|F_o|^2)^{-1}$ was introduced to obtain constant errors in the different ranges of $|F_o|$ values. Atomic scattering curves from ref. 9 were used. The final value of R was 0.099, and R' 0.124. A final difference-Fourier revealed ripples around the mercury atom but was otherwise featureless. Final atomic co-ordinates are listed in Table 1.

TABLE 1

Final atomic fractional co-ordinates

Atom	x	y	z
Hg	269.1(3)	386.1(3)	319.64(8)
S	297(3)	425(3)	48.6(7)
O(1)	300(4)	−18(4)	272(1)
O(2)	111(4)	−152(5)	203(2)
N	285(4)	429(4)	239(2)
C(1)	206(5)	8(6)	226(2)
C(2)	169(7)	246(7)	204(2)
C(3)	254(7)	232(8)	145(2)
C(4)	217(12)	460(14)	113(2)
C(5)	240(12)	697(12)	13(2)
C(6)	273(8)	383(11)	403(2)

Computer programs used in the structure analysis are listed in ref. 10. All computations were carried out on an I.B.M. 360/75 system in the University Computing Centre. Observed and calculated structure factors, and anisotropic thermal parameters, are listed in Supplementary Publication No. SUP 21951 (9 pp., 1 microfiche).*

RESULTS AND DISCUSSION

A perspective view of the molecular structure is shown in Figure 1. The amino-acid is co-ordinated to mercury *via* the amino-group rather than the thioether or carboxylate sites. The complex is thus a zwitterion, $MeHg^+H_2N{\cdot}CH(CO_2^-)CH_2{\cdot}CH_2{\cdot}SMe$. There is some interest in the strength of the Hg–N interaction since both amino-acid and peptide –NH– groups are potentially important binding sites in proteins.[11] However, despite the known affinity of Hg^{2+} for nitrogen donors [12] the ease of dissociation of pyridine from the methylmercury complex ion $[MeHg(py)]^+$ has prompted the comment that $MeHg^+$ should not bond strongly to protein-nitrogen donors.[13] The Hg–N bond length [2.06(4) Å] is somewhat shorter than expected from the sums of covalent radii, if the usual [14] tetrahedral value for Hg (1.50 Å) is assumed (see below) but is similar to the Hg–N distances in the amide $Hg(NH_2)Cl$ [2.05(2) Å],[15] $[(MeHg)_2(pen)]$ (pen = DL-penicillamine) [2.13(3) Å],[16] and mercury(II) succinimide (2.08 Å).[17] These values can thus be considered typical mercury–nitrogen distances in two-co-ordinate complexes. In contrast, values of Hg–N bond lengths [2.373(9) and 2.399(8) Å] in $[HgBr_2(bipy)_2]$ (ref. 18) and $[Hg(SCN)_2(phen)_2]$ [2.42—2.52(2) Å] (ref. 19) illustrate the much longer distances associated with higher co-ordination numbers. The mercury–carbon distance [2.11(5) Å] is in the expected range for methylmercury compounds.[10,20,21] If the Hg–C and Hg–N bonds are considered as single bonds and the radii of sp^3-hybridised carbon and nitrogen are taken to be 0.77 and 0.70 Å, the metal–ligand bond distances in the present complex are consistent with a covalent radius of *ca.* 1.35 Å for sp-hybridised mercury.

Although the co-ordination number of mercury is unequivocally two in this complex, the presence of two weak secondary interactions [Hg · · · O(2′) and Hg · · · O(1)] with carboxylate oxygen atoms (Figure 1) results in an N–Hg–C(6) angle significantly smaller than 180°. These contacts are only marginally bonding, when compared to the sums of van der Waals radii for mercury (1.50—1.73 Å) and oxygen (1.40 Å).[14] However, weak secondary interactions appear to be a feature of methylmercury amino-acid complexes, with intramolecular Hg · · · O and intermolecular Hg · · · S contacts present in [MeHg(cyst)] (cyst = L-cysteine) [10] and $[MeHg(pen)]{\cdot}H_2O$.[16]

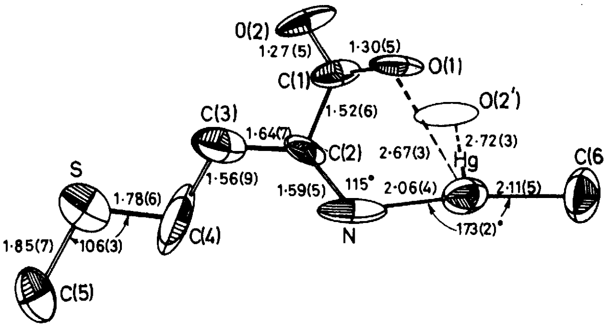

FIGURE 1 Molecular structure, bond distances (Å), and angles (°). Weak interactions around mercury are indicated by dashed lines. O(2′) is from a molecule at equivalent position $-x, \frac{1}{2} + y, \frac{1}{2} - z$

In the side-chain of the methionine complex, atoms C(2)—(5) and S form an almost planar zigzag chain which extends *trans* to the α carbon atom C(2). Distances and angles within the co-ordinated amino-acid compare favourably with values for the free ligand.[22]

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* See Notice to Authors No. 7, in *J.C.S. Dalton*, 1976, Index issue. (Items less than 10 pp. are supplied as full-size copies.)

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Hydrogen Bonding and Packing.—The hydrogen bonding system of the complex is simple. Each molecule contains two amino-hydrogen atoms available for hydrogen bonding. Around the nitrogen atom there are three contacts which are within the right order of distances for hydrogen bonding. Although the intramolecular oxygen O(1) has the shortest N · · · O distance, the angles Hg–N · · · O(1) [65.9(5)°] and C(2)–N · · · O(1) [63(2)°] are far from tetrahedral. It is therefore unlikely that O(1) is hydrogen-bonded to the nitrogen atom. The hydrogen bonding scheme is shown in Figure 2, where the nitrogen atom is hydrogen-bonded to two oxygen atoms from other molecules. One of the hydrogen bonds [N · · · O(2)] binds molecules separated by a unit translation along the *b* axis. Since the molecules are almost parallel to the *yz* plane, this forms a strip of hydrogen-bonded molecules which is parallel to the *yz* plane and extends along the *y* axis. Two antiparallel strips are then bound to each other *via* the other N · · · O(1) hydrogen bonds. The double strips pack into layers *via* the weak interactions of the SMe group along the *z* axis. Between these layers there are only weak van der Waals forces and disordered packing of these layers can easily occur. This explains the easy cleavage of the crystals along the (100) plane. Thick plate-like crystals are generally not single, owing to the presence of stacking faults in the layers.

TABLE 2

Some characteristic Raman and i.r. bands for [MeHg(met)], the deuteriated complex and the free ligand

(1) [a]		(2) [a]	(3) [a]		(4) [a]	
Raman	I.r.	I.r.	Raman	I.r.	I.r.	Assignments [b]
ca. 3 100vw, br	*ca.* 3 150w, sh *ca.* 3 050m, sh	*ca.* 2 200ms, br		3 160s, br	2 355ms 2 215ms	$\nu(NH^+)/\nu(ND_3^+)$
1 626w, br	1 623vs					$\delta_{asym}(NH_3^+)$
	1 513s					$\delta_{sym}(NH_3^+)$
		1 190 1 165				$\delta(ND_3^+)$
			1 252vw	1 590vs, br 1 250m, br	1 080ms, br 1 040w, br	$\delta(NH_2^+)/\delta(ND_2^+)$
1 576w, br	1 578vs, br 1 605vs, br	1 600vs, br		1 590vs, br 1 562s, sh	1 585vs, br 1 570vs, br	$\nu_{asym}(CO_2^-)$
1 416s	1 410vs	1 408vs	1 411vw	1 408m	1 392s	$\nu_{sym}(CO_2^-)$
523w, br	529vs	527vs	572vw	574m	564m	$\rho_r(CO_2^-)$
			543vs	542s, br	534ms, br	ν(Hg–C)
					518m	ν(Hg–N)

[a] (1) DL-methionine, (2) [$^2H_3$]methionine, (3) (DL-methioninato)methylmercury, (4) ([$^2H_2$]methioninato)methylmercury (deuterium exchange in amino-group). [b] ν Stretching mode, δ bending mode, ρ_t torsional mode, ρ_r rocking mode.

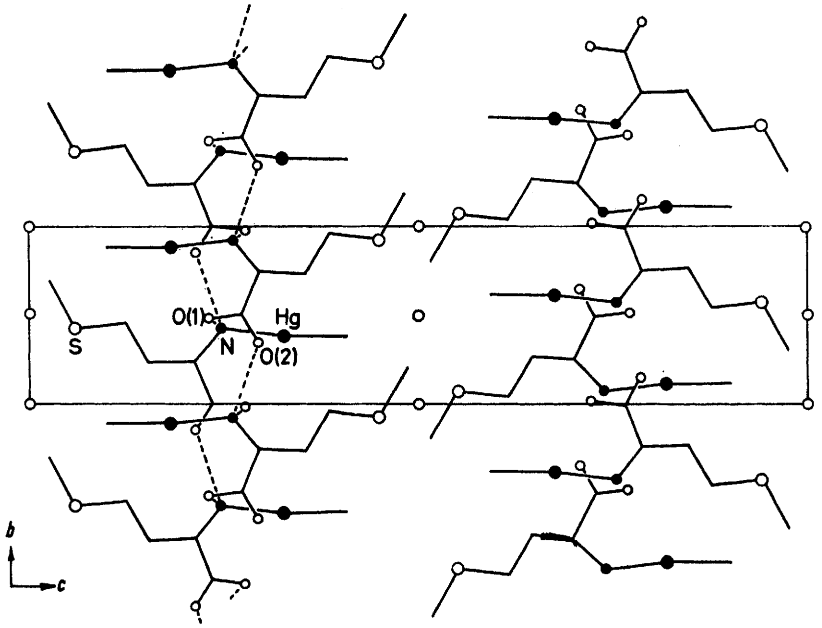

FIGURE 2 Packing and hydrogen-bonding

Raman and I.r. Spectra.—Characteristic Raman and i.r. bands for [MeHg(met)], the deuteriated complex, and the free ligand are shown in Table 2. Assignments for NH_2, NH_3^+, and CO_2^- vibrational modes follow those for the penicillamine complexes.[16] The frequency of ν(Hg–C) (542 cm^{-1}) is very similar to those for the sulphur-bonded complexes [MeHg(cyst)],[10] [MeHg(pen)]·H_2O, and [$(MeHg)_2$(pen)],[16] despite the differences in *trans*-ligands.

The literature data for ν(Hg–N) modes are quite confusing. Usually, the region from 400 to 700 cm^{-1} has been specified for this vibration.[23] Although strong bands at 543 (Raman) and 542 cm^{-1} (i.r.) were observed in the present complex, there was no other significant peak between 400 and 500 cm^{-1}. The same compound when crystallised from D_2O gave two bands at 534 and 518 cm^{-1}, the latter assigned to ν(Hg–N). The ν(Hg–N) mode in the undeuteriated species overlaps with the intense ν(Hg–C) mode, which should not be affected by deuterium exchange in the amino-group. These ν(Hg–N) frequencies are similar to those found for $[\text{MeHgNH}_3]^+$ at 585 cm^{-1} in the solid mull spectrum and 458 cm^{-1} for liquid ammonia solution.[24]

N.M.R. Spectra.—^{1}H and ^{13}C n.m.r. spectral data are given in Table 3. Both ^{1}H and ^{13}C chemical shifts for the SMe and $\gamma(\text{CH}_2)$ groups are about the same for free methionine and for the complex, whereas the changes for the α position $>$CH– are relatively large. In the complex, the organo-mercury group is adjacent to the α-position. There is a large shift in the ^{13}C resonance of the carboxylate carbon atom (from 176.8 to 181.0 p.p.m. relative to tetramethylsilane) possibly as a result of the weak Hg · · · O(carboxylate) interactions shown in Figure 1. The n.m.r. results indicate retention of mercury–nitrogen bonding for [MeHg(met)] in aqueous solution. This serves to confirm the results of Rabenstein and Fairhurst[6] for neutral aqueous solutions of $[\text{MeHg}]^+$ and methionine.

TABLE 3

N.m.r. data (δ/p.p.m. relative to tetramethylsilane) for (DL-methioninato)methylmercury(II) and for the free ligand; α, β, γ indicate positions with respect to the carboxylic group

Compound	α	β	γ	S–Me	Hg–Me	CO_2^-
(*a*) ^{1}H N.m.r.						
[MeHg(OH)]					0.87	
DL-met	3.87	2.22	2.67	2.13		
[MeHg(met)]	4.17	2.18	2.67	2.13	0.87	
(*b*) ^{13}C N.m.r.						
DL-met	56.5	32.3	31.5	16.6		176.8
[MeHg(met)]	58.4	34.8	32.1	16.9	0.9	181.0

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