Preparation and Structural Characterization of Methylmercury(II) Complexes of the Minor tRNA-Base 7-Methylguanine

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Abstract

Methylmercury(II) complexes of 7-methylguanine (7mguaH) have been isolated from aqueous solution in the pH range 1–12 and structurally characterized. 1:1 complexes $[(7mgua)HgCH_3]\cdot 2H_2O$ and $[(7mguaH)HgCH_3][NO_3]\cdot H_2O$ with respectively N1- and N9-coordination (X-ray analyses) were obtained from solutions in the respective pH ranges 9–12 and 1–4. A 2:1 complex $[(7mgua)(HgCH_3)_2][NO_3]$ with N1,N9-coordination (X-ray) may be prepared in the intermediate pH range 4–7. Two 3:1 complexes were isolated: $[(7mgua)(HgCH_3)_3][NO_3]_2$ from strongly acid solution (pH = 1–3), and $[(7mguaH_{-1})(HgCH_3)_3][NO_3]$ in the pH range 7–9. Whereas an X-ray analysis establishes N1,N3,N9-coordination for the former species in the solid state, the ^1H NMR data suggest N2,N3,N9-coordination for the former and N2,N2,N9-coordination for the latter species in d_6-DMSO solution.

Introduction

Minor nucleobases have been detected in all types of polynucleotides [1]. Characteristic modifications of the parent purines and pyrimidines are: the alkylation of amino groups; the methylation of ring nitrogen atoms, such as the N1 of adenine, N7 of guanine and N3 of cytosine; or replacement of the keto by thioketo groups. The biological role of many of the minor methylated bases is still uncertain. However, it has recently been suggested that the presence of 7-methylguanine is necessary to optimize the activity of important functional regions of rRNA [2]. Furthermore, it is now well documented that the percentage occurrence of alkylated nucleobases is significantly increased in certain tumour arts [3]. Carcinogenic agents such as *N*-nitrosodimethylamine have been demonstrated to select the N7 of guanine as a preferred methylation site [4].

The relative degree and position of alkylation can lead to pronounced changes in the metal binding proclivities of the available heteroatoms in purine bases [5, 6]. For instance, the logarithmic formation constant for the binding of 3-methyladenine to the bis(acetylacetonato)nitrocobalt(III) moiety is approximately twice as large as that for the isomeric 9-methyladenine [5, 6]. Studies of metal coordination to 7-methylguanine [7mguaH] have been very limited. N7 is well characterized as the preferred metal binding site for neutral N9-substituted guanine bases. A simple consideration of resonance hybrids suggests that if N7 is substituted instead of N9, the latter nitrogen should become available as a potential coordination position. Woollins and Rosenberg [7] have recently reported the preparation of a series of *cis*-diammineplatinum(II) complexes of the 7-methylguanine anion. On the basis of ^1H and ^{195}Pt NMR spectroscopy, N1,N9-binding was postulated for the presumably dimeric 1:1 species $[7mgua\{Pt(NH_3)_2\}][NO_3]\cdot nH_2O$ ($n = 1$ or 5). N3, N9- and N1,N9-coordination were proposed for two 2:1 species, the former of which is converted quantitatively to the latter in less than 60 min in aqueous solution. The interaction of Ag^+ ions with 7-methylguanine in aqueous solution has been studied by Matsuoka and Norden [8]. UV and IR spectroscopic data were interpreted as supporting the presence of centrosymmetric dimers $[(7mgua)Ag]_2$ in which the silver cations are coordinated by both N1 and O6. No X-ray structural analyses have been performed on metal complexes of 7-methylguanine.

On account of its ability to function as a uniligating Lewis acid with minimal steric effects, the CH_3Hg^+ ion has proved to be a suitable cation for the analytical characterization of binding sites in nucleotides and nucleobases [9–12]. A systematic study [13] of the interaction of 9-methylguanine (9mguaH) with CH_3Hg^+ led to the isolation of the following four complexes: $[(9mgua)HgCH_3]$, $[(9mguaH)HgCH_3][NO_3]$, $[(9mguaH)HgCH_3]\cdot H_2O$ and $[(9mgua)(HgCH_3)_2][NO_3]$ with respectively N1-, N7-, N7- and N1,N7-coordination. An X-ray analysis was performed on the second complex. No evidence was presented for mercury coordination of either the ring nitrogen N3 or the exocyclic nitrogen N2.

We now report a systematic analysis of the interaction of CH_3Hg^+ with 7-methylguanine. We present the preparation and ^1H NMR characterization of

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the complexes $[(7mgua)HgCH_3]\cdot 2H_2O$ (**1n·2H₂O**), $[(7mguaH)HgCH_3][NO_3]\cdot H_2O$ (**1i·H₂O**), $[(7mgua)(HgCH_3)_2][NO_3]$ (**2i**), $[(7mguaH_{-1})(HgCH_3)_3][NO_3]$ (**3i**) and $[(7mgua)(HgCH_3)_3][NO_3]_2$ (**3ii**). In addition, X-ray structural analyses were carried out on the complexes **1n·2H₂O**, **1i·H₂O**, **2i** and **3ii**.

Experimental

Methylmercury(II) hydroxide (Alfa) and 7-methylguanine (Sigma) were used as received. The analytical and ^1H NMR data for the methylmercury(II) complexes are presented in Tables I and II. IR spectra were recorded as 1% KBr discs on a Perkin-Elmer 297 spectrometer.

TABLE I. Analytical Data for Methylmercury(II) Complexes of 7-Methylguanine [found (calc.) (%)][a]

Compound	C	H	N
1n·2H₂O	20.1 (20.22)	3.01 (3.15)	16.8 (16.84)
1i·H₂O	18.0 (18.24)	2.60 (2.63)	18.1 (18.24)
2i	14.5 (14.62)	1.88 (1.84)	12.8 (12.78)
3i	11.7 (11.56)	1.61 (1.62)	10.3 (10.49)
3ii	11.7 (11.56)	1.61 (1.62)	10.3 (10.49)

[a]Microanalyses were performed with a Perkin-Elmer 240.

Preparation of Methylmercury(II) Complexes

All preparations were carried out at ambient temperature in a well-ventilated fume hood. In a typical experiment, 0.27 mmol (0.061 g) methylmercury(II) hydroxide was added to an appropriate suspension of 7-methylguanine in 5 ml H_2O to yield the required metal-to-ligand ratio. The pH of the solution was adjusted to a predetermined value by addition of either 1 M HNO_3 or NaOH. Complete solution was achieved for pH values below 5 or greater than 10. In the intermediate range, filtration was necessary to yield a clear solution. Slow evaporation of the solutions yielded the following complexes:

$[(7mgua)HgCH_3]\cdot 2H_2O$ (**1n·2H₂O**), 0.8:1 ratio, pH = 9–12

$[(7mguaH)HgCH_3][NO_3]\cdot H_2O$ (**1i·H₂O**), 0.8:1 ratio, pH = 1–4

$[(7mguaH)HgCH_3)_2][NO_3]$ (**2i**), 3:1 ratio, pH = 4–6

$[(7mguaH_{-1})(HgCH_3)_3][NO_3]$ (**3i**), 3:1 ratio, pH = 7–9

$[(7mgua)(HgCH_3)_3][NO_3]_2$ (**3ii**), 2:1 ratio, pH = 1–3

Compound **2i** is also obtained for a 1:1 ratio in the pH range 6–7, and **3i** for a 2:1 ratio in the pH range 8–9. The colourless crystalline precipitates were washed with ethanol and ether. Satisfactory microanalyses (Table I) were obtained for all complexes.

X-ray Structural Analysis

Crystal and refinement data for **1n·2H₂O**, **1i·H₂O**, **2i** and **3ii** are summarized in Table III. Unit cell constants were obtained from a least-squares fit to the settings of 25 reflections recorded on an Enraf-Nonius CAD4 diffractometer. Intensities were collected on the diffractometer at varied scan rates in the θ–2θ or ω-mode with graphite-monochromated Mo Kα radiation ($\lambda = 0.71073$ Å). Three monitor reflections were measured at regular intervals; crystal decay was not observed. Empirical absorption corrections were applied to the reflection intensities of all data sets. The structures were solved by Patterson (**1n·2H₂O**, **1i·H₂O**, **2i**) or direct methods (**3ii**) and refined by full-matrix least-squares. Difference syntheses failed to reveal unequivocal positions for all hydrogen atoms in the methylmercury(II) complexes and these atoms were not, therefore, included in the final refinement cycles. Anisotropic temperature factors were introduced for the mercury atoms. The terminal reliability indices are listed in Table III, where $R_w = [\Sigma w(F_o - F_c)^2/\Sigma w F_o^2]^{1/2}$. Weights were applied using the expression $w = (\sigma^2(F_o) + p^2F_o^2)^{-1}$, with values of p as given in Table III. Calculations were carried out

TABLE II. ^1H NMR Data for Methylmercury(II) Complexes of 7-Methylguanine[a]

Compound	δ(H2)	δ(H8)	δ(CH_3)	δ(Hg–CH_3)	$^2J(^{199}Hg-^1H)$ (Hz)
7-Methylguanine	6.09	7.83	3.82		
1n·2H₂O	6.03	7.73	3.81	0.75	207.5
1i·H₂O	6.91	8.39	3.98	0.83	211
2i	7.13	8.23	3.94	0.82	220
3i		8.06	3.90	0.77	206.5
3ii	7.32	8.28	3.95	0.83	234.5

[a]Spectra were recorded on a Bruker WP 200 spectrometer at 20 °C in saturated solutions of d_6-DMSO using internal TMS references. All shifts are in ppm downfield from TMS. Satisfactory integration of all spectra was obtained.

TABLE III. Crystal and Refinement Data for Methylmercury(II) Complexes of 7-Methylguanine

Compound	**1n·2H$_2$O**	**1i·H$_2$O**	**2i**	**3ii**
Space group	$P2_1/c$	$P\bar{1}$	$P\bar{1}$	$P\bar{1}$
a (Å)	11.375(3)	8.667(3)	9.556(1)	11.101(3)
b (Å)	13.732(3)	10.232(3)	10.684(2)	15.746(5)
c (Å)	7.471(2)	7.112(3)	7.181(2)	11.042(5)
α (°)	90	90.38(3)	108.58(2)	90.51(5)
β (°)	105.54(2)	100.35(3)	94.83(2)	91.62(4)
γ (°)	90	91.93(3)	82.86(1)	73.12(4)
V (Å^3)	1124(1)	620.0(8)	688.8(4)	1846(2)
Z	4	2	2	4
D_c (g cm^{-3})	2.46	2.47	3.17	3.36
Radiation	Mo Kα	Mo Kα	Mo Kα	Mo Kα
μ (cm^{-1})	136.9	124.4	222.8	249.3
Scan method	ω	$\theta-2\theta$	ω	ω
$2\theta_{max}$ (°)	50	50	45	45
Reflections measured	1971	2183	1814	4809
Reflections observed	1592	1908	1387	3299
Rejection criterion	$F_o^2 < 2\sigma(F_o^2)$	$F_o^2 < 2\sigma(F_o^2)$	$F_o^2 < 2\sigma(F_o^2)$	$F_o^2 < 2\sigma(F_o^2)$
R	0.042	0.037	0.065	0.062
R_w	0.043	0.034	0.056	0.061
p	0.005	0.005	0.002	0.005

with MULTAN-82 [14], with the SDP suite (Enraf-Nonius) and with local programs. Diagrams were drawn with RSPLOT [15]. Atomic positional parameters with isotropic temperature factors are listed in Table IV and the coordination geometries of the mercury atoms in Table V.

TABLE IV. Atomic Positional Parameters with Equivalent Isotropic Temperature Factors (Å^2)

Atom	x/a	y/b	z/c	B_{eq}
1n·2H$_2$O				
Hg1	0.0979(1)	0.1057(1)	0.1184(1)	2.5(1)
O6	0.1590(7)	−0.0314(7)	0.4230(12)	2.8(2)
N1	0.2537(7)	0.0173(8)	0.2036(13)	1.7(2)
N2	0.3450(8)	0.0706(8)	−0.0215(14)	2.7(2)
N3	0.4497(7)	−0.0404(8)	0.1978(13)	2.0(2)
N7	0.3936(8)	−0.1490(8)	0.5927(14)	2.4(2)
N9	0.5435(8)	−0.1489(8)	0.4502(14)	2.4(2)
C2	0.3510(10)	0.0133(11)	0.1316(17)	2.5(3)
C4	0.4506(9)	−0.0917(10)	0.3515(16)	2.1(2)
C5	0.3574(9)	−0.0899(10)	0.4381(16)	2.1(2)
C6	0.2524(9)	−0.0331(10)	0.3658(17)	2.2(2)
C7	0.3281(10)	−0.1640(11)	0.7381(18)	3.0(3)
C8	0.5061(10)	−0.1844(11)	0.5952(17)	2.7(3)
C11	−0.0581(11)	0.1879(12)	0.0404(19)	3.3(3)
Ow1	0.2187(9)	0.2204(9)	0.5322(16)	5.6(3)
Ow2	0.0917(8)	0.0704(8)	−0.2977(14)	4.7(2)
1i·H$_2$O				
Hg9	0.2270(1)	0.1529(1)	0.1997(1)	3.4(1)
O6	−0.2829(7)	0.6273(6)	0.1765(9)	4.5(1)
O11	0.8761(7)	0.8790(7)	0.4456(10)	4.9(2)
O12	0.9369(7)	0.9543(7)	0.1871(9)	4.6(1)
O13	0.7834(7)	1.0615(7)	0.3316(9)	4.8(2)
N1	−0.0270(8)	0.6531(7)	0.3099(10)	3.1(1)
N2	0.2351(8)	0.6970(8)	0.4401(11)	3.8(2)

(continued)

TABLE IV. *(continued)*

Atom	*x/a*	*y/b*	*z/c*	B_{eq}
1i·H_2O				
N3	0.1625(7)	0.4887(7)	0.3124(9)	2.8(1)
N7	−0.1980(7)	0.3451(7)	0.0858(10)	3.0(1)
N9	0.0461(7)	0.2884(7)	0.1662(10)	3.0(1)
N10	0.8635(8)	0.9662(8)	0.3197(10)	3.7(2)
C2	0.1239(9)	0.6079(9)	0.3518(12)	3.1(2)
C4	0.0367(9)	0.4135(8)	0.2226(12)	2.8(2)
C5	−0.1118(9)	0.4521(9)	0.1754(12)	2.8(2)
C6	−0.1527(10)	0.5785(9)	0.2132(12)	3.3(2)
C7	−0.3715(11)	0.3384(10)	0.0134(14)	4.4(2)
C8	0.1025(10)	0.2482(9)	0.0790(13)	3.5(2)
C91	0.3951(11)	0.0133(10)	0.2196(14)	4.6(2)
Ow1	0.4296(7)	0.3422(7)	0.4913(10)	5.0(2)
2i				
Hg1	0.7194(1)	0.4130(1)	0.0277(2)	3.0(1)
Hg9	0.2090(1)	−0.1124(1)	−0.4772(2)	2.7(1)
O6	0.5300(22)	0.4291(22)	−0.2932(33)	4.3(5)
O11	0.0163(28)	0.9524(29)	0.2535(43)	7.8(8)
O12	−0.1436(29)	0.9029(31)	0.0763(45)	8.3(9)
O13	0.0595(32)	0.7777(33)	−0.0311(49)	9.6(10)
N1	0.5864(24)	0.2756(24)	−0.1238(36)	2.9(6)
N2	0.6397(24)	0.1286(25)	0.0355(37)	3.3(6)
N3	0.4589(22)	0.0808(23)	−0.2125(34)	2.3(5)
N7	0.3286(26)	0.2301(26)	−0.5640(39)	3.8(6)
N9	0.2923(21)	0.0594(22)	−0.4611(33)	2.0(5)
N11	−0.0133(27)	0.8760(28)	0.0921(41)	4.4(7)
C11	0.8559(31)	0.5456(32)	0.1739(47)	3.7(8)
C2	0.5532(29)	0.1661(30)	−0.0959(44)	2.7(7)
C4	0.3897(25)	0.1231(26)	−0.3606(39)	1.7(6)
C5	0.4169(28)	0.2267(29)	−0.3928(43)	2.3(6)
C6	0.5105(29)	0.3140(29)	−0.2744(45)	2.9(7)
C7	0.3207(35)	0.3266(36)	−0.6915(54)	4.6(9)
C8	0.2573(29)	0.1211(30)	−0.6041(46)	2.9(7)
C91	0.1465(31)	−0.2840(33)	−0.4910(48)	3.5(8)
3ii				
Hg1A	0.0563(2)	0.1196(1)	0.2062(2)	3.2(1)
Hg3A	−0.1536(1)	0.1866(1)	0.7236(1)	2.9(1)
Hg9A	−0.4185(1)	0.3348(1)	0.7164(2)	3.4(1)
O6A	−0.1587(24)	0.2654(17)	0.1697(26)	4.8(7)
N1A	−0.0703(25)	0.1856(18)	0.3352(27)	3.0(7)
N2A	0.0313(24)	0.1097(17)	0.5048(27)	2.5(6)
N3A	−0.1552(24)	0.2076(17)	0.5384(27)	2.6(6)
N7A	−0.3901(25)	0.3465(18)	0.3351(27)	2.8(7)
N9A	−0.3690(24)	0.3180(17)	0.5325(26)	2.3(6)
C2A	−0.0665(35)	0.1691(24)	0.4647(39)	3.8(9)
C4A	−0.2616(30)	0.2669(21)	0.4825(33)	2.6(8)
C5A	−0.2702(31)	0.2832(22)	0.3554(34)	2.7(8)
C6A	−0.1712(30)	0.2500(22)	0.2834(33)	2.5(8)
C7A	−0.4417(36)	0.3829(25)	0.2053(40)	4.4(10)
C8A	−0.4494(32)	0.3644(23)	0.4428(35)	3.2(9)
C11A	0.1924(36)	0.0660(25)	0.0802(39)	4.2(10)
C31A	−0.1535(40)	0.1663(28)	0.9107(44)	5.5(12)
C91A	−0.4622(39)	0.3444(27)	0.8895(43)	5.1(11)
Hg1B	0.9530(2)	0.4097(1)	0.1422(2)	3.6(1)
Hg3B	1.1217(1)	0.2835(1)	0.6608(2)	3.2(1)
Hg9B	1.3916(1)	0.1388(1)	0.6621(2)	3.7(1)

(continued)

TABLE IV. *(continued)*

Atom	*x/a*	*y/b*	*z/c*	B_{eq}
3ii				
O6B	1.2140(24)	0.3049(17)	0.1011(27)	5.1(7)
N1B	1.0965(26)	0.3366(19)	0.2672(29)	3.5(7)
N2B	0.9492(27)	0.3874(19)	0.4337(29)	3.5(7)
N3B	1.1546(24)	0.2825(17)	0.4741(26)	2.4(6)
N7B	1.4094(25)	0.1869(17)	0.2852(27)	2.7(7)
N9B	1.3654(25)	0.1776(18)	0.4834(28)	3.0(7)
C2B	1.0639(34)	0.3372(25)	0.3903(38)	4.0(9)
C4B	1.2635(32)	0.2362(23)	0.4186(35)	3.1(8)
C5B	1.2920(33)	0.2409(24)	0.3021(36)	3.4(9)
C6B	1.2012(33)	0.2954(23)	0.2136(35)	3.2(9)
C7B	1.4735(37)	0.1647(26)	0.1644(41)	4.7(10)
C8B	1.4525(32)	0.1492(23)	0.4016(35)	3.2(9)
C11B	0.8253(37)	0.4731(26)	0.0176(42)	4.8(11)
C31B	1.0876(35)	0.2749(25)	0.8418(39)	4.0(10)
C91B	1.4057(44)	0.1068(31)	0.8474(49)	6.8(14)
O11	0.3757(27)	−0.0024(19)	0.4048(29)	6.2(8)
O12	0.3652(21)	−0.1355(15)	0.3684(23)	3.2(6)
O13	0.1928(22)	−0.0289(16)	0.3612(25)	4.1(6)
O21	0.6585(24)	0.6555(17)	0.3567(27)	4.9(7)
O22	0.6549(28)	0.5197(19)	0.3515(31)	7.0(9)
O23	0.8363(23)	0.5524(16)	0.3226(26)	4.5(7)
O31	0.1596(30)	0.6220(21)	0.3212(33)	8.1(10)
O32	0.3314(38)	0.5180(25)	0.3026(41)	11.5(13)
O33	0.1660(41)	0.4953(28)	0.3644(46)	15.4(15)
O41	0.7493(31)	0.0184(21)	0.3410(33)	8.1(10)
O42	0.7796(28)	0.0784(19)	0.1726(31)	7.0(9)
O43	0.9419(27)	−0.0234(19)	0.2644(30)	6.6(8)
N10	0.3132(27)	−0.0563(19)	0.3816(30)	3.7(7)
N20	0.7206(31)	0.5775(22)	0.3412(34)	5.5(9)
N30	0.2126(38)	0.5457(26)	0.3179(42)	8.5(12)
N40	0.8213(34)	0.0240(23)	0.2529(37)	6.5(10)

TABLE V. Bond Lengths (Å) and Angles to the Mercury Atoms

1n·2H$_2$O			
Hg1–N1	2.101(5)	Hg1–C11	2.051(8)
Hg1–O6	2.892(6)	Hg1–Ow1[a]	2.911(7)
Hg1–Ow2	3.128(7)		
N1–Hg1–C11	177.6(3)	N1–Hg1–O6	51.7(2)
N1–Hg1–Ow1	97.5(2)	N1–Hg1–Ow2	90.2(2)
C11–Hg1–O6	126.1(3)	C11–Hg1–Ow1	84.8(3)
C11–Hg1–Ow2	90.9(3)	O6–Hg1–Ow1	132.9(2)
O6–Hg1–Ow2	128.2(2)	Ow1–Hg1–Ow2	78.1(2)
[a]denotes $x, \frac{1}{2}-y, -\frac{1}{2}+z$			
1i·H$_2$O			
Hg9–N9	2.111(4)	Hg9–C91	2.062(7)
Hg9–Ow1	3.090(5)	Hg9–O11[a]	2.841(5)
Hg9–O12[b]	3.040(4)	Hg9–O12[c]	3.167(4)
N9–Hg9–C91	176.4(2)	N9–Hg9–Ow1	89.1(2)
N9–Hg9–O11[a]	80.2(2)	N9–Hg9–O12[b]	85.0(2)
N9–Hg9–O12[c]	81.2(2)	C91–Hg9–Ow1	94.5(2)
C91–Hg9–O11[a]	101.0(2)	C91–Hg9–O12[b]	91.6(2)

(continued)

TABLE V. *(continued)*

1i·H_2O			
C91–Hg9–O12[c]	96.2(2)	Ow1–Hg9–O11[a]	72.7(1)
Ow1–Hg9–O12[b]	158.2(1)	Ow1–Hg9–O12[c]	137.9(1)
O11[a]–Hg9–O12[b]	126.6(1)	O11[a]–Hg9–O12[c]	65.3(1)
O12[b]–Hg9–O12[c]	61.8(1)		

[a]denotes $1-x, 1-y, 1-z$. [b]$1-x, 1-y, \bar{z}$. [c]$-1+x, -1+y, z$.

2i			
Hg1–N1	2.04(2)	Hg1–C11	2.02(3)
Hg1–O6	2.84(2)	Hg1–O6[a]	3.14(2)
H1–O13[a]	2.75(3)	Hg9–N9	2.06(3)
Hg9–C91	1.97(4)	Hg9–O11[b]	2.75(3)
Hg9–O11[c]	2.84(3)	Hg9–O12[c]	3.09(3)
N1–Hg1–C11	178(1)	N1–Hg1–O6	54(1)
N1–Hg1–O6[a]	89(1)	N1–Hg1–O13[a]	93(1)
C11–Hg1–O6	127(1)	C11–Hg1–O6[a]	93(1)
C11–Hg1–O13[a]	86(1)	O6–Hg1–O6[a]	85(1)
O6–Hg1–O13[a]	128(1)	O6[a]–Hg1–O13[a]	139(1)
N9–Hg9–C91	175(1)	N9–Hg9–O11[b]	85(1)
N9–Hg9–O11[c]	88(1)	N9–Hg9–O12[c]	71(1)
C91–Hg9–O11[b]	99(1)	C91–Hg9–O11[c]	96(1)
C91–Hg9–O12[c]	111(1)	O11[b]–Hg9–O11[c]	75(1)
O11[b]–Hg9–O12[c]	106(1)	O11[c]–Hg9–O12[c]	37(1)

[a]denotes $1-x, 1-y, \bar{z}$. [b]$x, -1+y, -1+z$. [c]$\bar{x}, 1-y, \bar{z}$.

3ii			
Hg1A–N1A	2.08(2)	Hg1A–C11A	2.07(3)
Hg1A–O6A	2.81(2)	Hg1A–O13	2.93(2)
Hg1A–O43[a]	2.97(2)	Hg3A–N3A	2.07(2)
Hg3A–C31A	2.09(3)	Hg3A–O12[b]	2.85(2)
Hg3A–O13[b]	2.79(2)	Hg3A–O31[c]	3.04(2)
Hg3A–O43[d]	2.94(2)	Hg9A–N9A	2.11(2)
Hg9A–C91A	1.98(3)	Hg9A–O21[c]	2.72(2)
Hg9A–O22	3.02(2)	Hg9A–O32[c]	2.77(3)
Hg1B–N1B	2.08(2)	Hg1B–C11B	2.00(3)
Hg1B–O6B	2.93(2)	Hg1B–O6A[e]	2.91(2)
Hg1B–O23	3.01(2)	Hg3B–C31B	2.06(3)
Hg3B–O21[f]	2.88(2)	Hg3B–O23[f]	2.76(2)
Hg3B–O31[g]	3.06(2)	Hg9B–N9B	2.06(2)
Hg9B–C91B	2.10(3)	Hg9B–O11[h]	2.95(2)
Hg9B–O12[h]	2.72(2)	Hg9B–O21[f]	3.13(2)
N1A–Hg1A–C11A	173(1)	N3A–Hg3A–C31A	179(1)
N9A–Hg9A–C91A	177(1)	N1B–Hg1B–C11B	177(1)
N3B–Hg3B–C31B	176(1)	N9B–Hg9B–C91B	176(1)

[a]denotes $-1+x, y, z$. [b]$\bar{x}, y, 1-z$. [c]$\bar{x}, 1-y, 1-z$. [d]$1-x, \bar{y}, 1-z$. [e]$1+x, y, z$. [f]$2-x, 1-y, 1-z$. [g]$1-x, 1-y, 1-z$. [h]$2-x, \bar{y}, 1-z$.

Discussion

As was observed for 9-methylguanine, N1 is the preferred binding site for the CH_3Hg^+ ion with 7-methylguanine in neutral or alkaline solution. However, the 1:1 neutral complex **1n·2H_2O** can only be isolated at pH values above 9. The 2:1 ionic species **2i** is obtained for a 1:1 ratio in the pH range 6–7. In neutral and alkaline solutions of methylmercury(II), CH_3HgOH is the predominant species. In addition to CH_3HgOH, a significant concentration of $[(CH_3Hg)_2OH]^+$ will be present in the pH range 4–7, CH_3Hg^+ being only of importance in more acid solutions [16].

$$CH_3HgOH + HN< \rightleftharpoons CH_3HgN< + H_2O \quad (1)$$

$$CH_3HgOH + N\leqslant \rightleftharpoons CH_3HgN^{+}\leqslant + OH^- \quad (2)$$

$$CH_3Hg^+ + HN< \rightleftharpoons CH_3HgN< + H^+ \quad (3)$$

$$CH_3Hg^+ + N\leqslant \rightleftharpoons CH_3HgN\overset{+}{\leqslant} \quad (4)$$

At pH values above 9 reaction (1) prevails leading to the formation of neutral species. Whereas the equilibrium for this reaction is independent of the pH value, it will be shifted to the right in the second case as the pH decreases in the range 12–6. The isolation of the complexes **2i** and **3i** for less than stoichiometric ratios in the respective pH ranges 6–7 and 8–9 emphasises that reactions (1) and (2) must be competitive in neutral aqueous solutions. The 1:1 ionic species **1i·H$_2$O** is formed by reaction (4) at pH values below 4. However, substitution of an N-proton is still possible even in markedly acid solution, either by reaction (2) or (3), as evidenced by the preparation of **3ii** in the pH range 1–3.

The crystal structure analysis of **1n·2H$_2$O** confirms N1-coordination (Fig. 1). In addition to the methyl carbon C11, the coordination sphere of Hg1 is completed by weak secondary bonds to O6 and the water molecules of crystallization Ow1 and Ow2. Small upfield shifts with respect to 7-methylguanine itself are registered in the ^{1}H NMR spectrum for both the H2 and H8 signals.

In the 1:1 ionic species **1i·H$_2$O**, N9 is the metal binding site in the solid state. Translation-equivalent mercury atoms are linked via secondary Hg···O bonds to nitrate oxygen atoms into chains parallel to the direction of the *c*-axis (Fig. 2). As a result of the introduction of a positive charge, marked downfield shifts are observed for the H2 and H8 signals in the ^{1}H NMR spectrum in comparison. In both the free base and **1i·H$_2$O** no signal can be located for H1. The strength of metal binding in methylmercury(II) complexes is reflected in the magnitude of the $^2J(^{199}Hg-^1H)$ coupling constants. Lower values are associated with an increased Hg–N bond strength. The observed value of 211.0 for **1i·H$_2$O** is larger than that of 207.5 in **1n·2H$_2$O**, as would be expected on account of the lower basicity of N9 in comparison to N1. As for 9-methylguanine, a 2:1 ionic species could also be isolated for 7-methylguanine (in the intermediate pH range 4–7); X-ray structural analysis established N1,N9-coordination. In the crystal lattice the cations are linked via weak intermolecular Hg···O6 interactions of length 3.14(2) Å into centrosymmetric dimers. Secondary bonding between mercury and nitrate oxygen atoms leads to the formation of sheets as depicted in Fig. 3. Marked downfield shifts are registered in the ^{1}H NMR spectrum for both the H2 and H8 signals in comparison to **1n·2H$_2$O**. Surprisingly, δ(H2) is also 0.22 ppm downfield from its position in **1i·2H$_2$O**. The coupling constant $^2J(^{199}Hg-^1H)$ is significantly larger in **2i** than in **1n·2H$_2$O** or **1i·H$_2$O**, indicating that the average strength of the Hg–N bonds in the 2:1 ionic species is considerably weaker than in either of the 1:1 species.

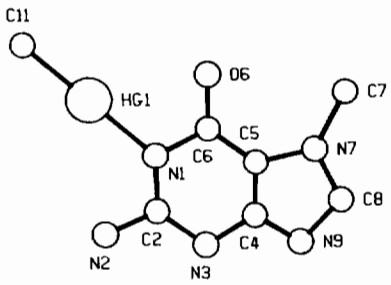

Fig. 1. N1-coordination in the complex **1n·2H$_2$O**.

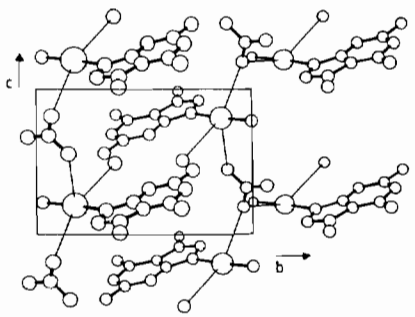

Fig. 2. Projection of the unit cell contents of the complex **1i·H$_2$O** perpendicular to [100].

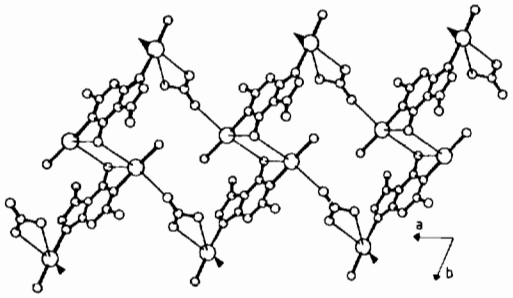

Fig. 3. Projection of the unit cell contents of the complex **2i** perpendicular to [001].

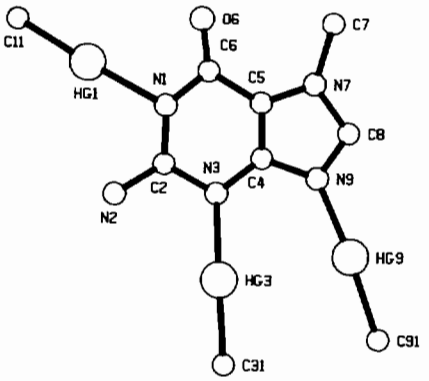

Fig. 4. Structure of cation B of complex **3ii**.

In contrast to 9-methylguanine, for which no 3:1 complexes were reported, both **3i** and **3ii** could be prepared for 7-methylguanine. The ^{1}H NMR spectrum for **3i** in d_6-DMSO establishes that both N2-amino protons have been substituted by CH_3Hg^+, indicating N2,N2,N9-coordination. Unfortunately, it proved impossible to grow crystals of **3i** suitable for X-ray structural analysis. This was, however, possible for the second 3:1 species **3ii**, which crystallizes with two independent cations in the unit cell. The structure of the second cation is depicted in Fig. 4. In contrast to the N1,N3,N9-coordination in the solid state, integration of the ^{1}H NMR spectrum for **3ii** in d_6-DMSO establishes unequivocally a 1:1 ratio for δ(H2) and δ(H8), indicating that one of the amino protons is substituted by CH_3Hg^+. Once again no signal could be located for H1. Thus isomerization of **3ii** from N1,N3,N9- to N2,N3,N9-coordination must occur upon solution in d_6-DMSO. In view of the fact that N1 is coordinated in the complex **2i**, which may be prepared in the pH range 4–7, it seems reasonable to suppose that **3i** will be obtained as the N1,N2,N9-isomer from aqueous solution. As for **3ii**, isomerization will then occur in d_6-DMSO. The greater basicity of N2 in comparison to N1 is indicated by the value of 206.5 Hz for $^2J(^{199}Hg-^1H)$ in **3i**, which is even smaller than in the neutral species **1n·2H$_2$O** (207.5 Hz). In contrast, an average value of 234.5 Hz is recorded for the dication of **3ii**.

Our results indicate that, as for 9-methylguanine, the unsubstituted nitrogen in the imidazole ring will be the preferred binding site for neutral 7-methylguanine, e.g. N9 in **1i·H$_2$O**. Likewise, the N1-proton may be substituted by CH_3Hg^+ at higher pH values. However, our present work also establishes N2 and N3 as secondary binding sites for CH_3Hg^+ with 7-methylguanine. Coordination of these nitrogen atoms was not reported for 9-methylguanine [13]. We intend, therefore, to carry out a similar study on 9-methylguanine in order to ascertain whether the site of guanine methylation does indeed lead to significant changes in the pattern of secondary metal binding.

Supplementary Material

Tables of anisotropic temperature factors, observed and calculated structure factors and IR data are available from the authors on request.

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