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Mono- and Polynuclear Guanine Complexes of Platinum(II). Syntheses and Crystal and Molecular Structures of Bis(9-methylguanine-*N*(7))bis(trimethylphosphine)platinum(II) Dinitrate and *cyclo*-Hexakis(9-methylguanine(-H)-*N*(1),*N*(7))hexakis(*cis*-bis-(trimethylphosphine)platinum(II)) Hexanitrate

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The synthesis and characterization of the guanine complexes *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu)_2](NO_3)_2$ and *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu(\text{-}H))]_6(NO_3)_6$ (9-MeGu and 9-MeGu(-H) are the neutral and the N(1)-deprotonated 9-methylguanine, respectively) are reported. The mononuclear derivative is formed by reacting 2 equiv of nucleobase with an aqueous solution of *cis*-$[(PMe_3)_2Pt(NO_3)_2]$ at autogenous pH, and it crystallizes from methanol in the tetragonal system, space group $P4_12_12$, with the following cell dimensions: $a = b = 11.106(4)$ Å, $c = 48.89(3)$ Å, $Z = 8$. The structure was solved using 3562 observed reflections and refined to $R = 3.98$ and $R_w = 5.02\%$. The nucleobases are N(7)-bonded to the metal center of the *cis*-$(PMe_3)_2Pt$ unit (Pt−P = 2.250(4) Å (average); Pt−N(7) = 2.11(1) Å; P−Pt−P = 96.2(2)°; N−Pt−N = 83.2(5)°) in a head-to-tail arrangement. The two purine rings are almost perpendicular to the metal-coordination plane (dihedral angles 83.6 and 101.7°) and form an intraligand dihedral angle of 77.6°. The hexanuclear complex is formed when equimolar amounts of *cis*-$[(PMe_3)_2Pt(NO_3)_2]$ and 9-MeGu are reacted at neutral pH. Crystallization of the crude product from water affords colorless prisms which crystallize as *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu(\text{-}H))]_6(NO_3)_6{\cdot}18H_2O$, in the hexagonal system, space group $R\bar{3}$, with the following cell dimensions: $a = b = 23.178$ (3) Å, $c = 24.937(3)$ Å, $Z = 3$. The structure was solved using 2094 independent observed reflections and refined to $R = 5.64$ and $R_w = 5.97\%$. The compound contains the cyclic cation *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu(\text{-}H))]_6^{6+}$ in which six *cis*-$(PMe_3)_2Pt$ units are symmetrically bridged by deprotonated guanine ligands through their N(1) and N(7) atoms. The hexamer, with an S_3 symmetry, exhibits the purine rings alternatively disposed above and below the mean plane passing through the metal atoms and forming with this plane an angle of 50°. The adjacent platinum atoms are disposed alternatively in two parallel planes, slightly separated (0.34 Å), at a minimum distance of 6.5 Å. Each metal atom is in a distorted square-planar arrangement defined by the phosphorus atoms of two PMe_3 moieties [(Pt−P = 2.245(7) Å (average); P−Pt−P = 94.9(2)°] and the N(1) [Pt−N(1) = 2.12(2) Å] and N(7)′ [Pt−N(7)′ = 2.09(1) Å; N(1)−Pt−N(7)′ = 83.4(5)°] atoms of two deprotonated guanine ligands. Both complexes have been further characterized by ^1H and ^{31}P NMR spectroscopy.

Introduction

Much is known about the interaction of the model nucleobase N(9)-substituted guanine with platinum electrophiles. At neutral pH, the purine N(7) atom is largely the preferred site for metal coordination, and a remarkable number of complexes containing this ligand have been described.[1] At higher pH values, the deprotonation of the nucleobase at the N(1) position (pK_a(N(1)H) = 9.4)[2] makes a second metal-binding site available, and the formation of N(1),N(7)-diplatinated guanine adducts has been frequently observed and in a few cases structurally characterized.[3] Moreover, it has been shown that the platination of the N(7) site increases the nucleophilicity of the N(3) atom, leading in some cases to the simultaneous coordination of three metal centers to the N(7), N(1), and N(3) sites of the purine ring.[4]

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As part of our study on the reactivity of platinum(II)–phosphino complexes toward nucleobases and nucleosides, we recently reported that the water-soluble complex *cis*-$[(PMe_3)_2Pt(NO_3)_2]$ reacts with 1-methyl-substituted cytosine (1-MeCy) to give, in dependence on the pH, the adducts *cis*-$[(PMe_3)_2Pt(1\text{-MeCy})_n]^{2+}$ ($n = 1, 2$)[5] and *cis*-$[(PMe_3)_2Pt(1\text{-MeCy}(\text{-H}))]_n^{n+}$ ($n = 2, 3$)[6] . Structural investigations have established that in the polynuclear complexes the NH_2-deprotonated nucleobase (1-MeCy(-H)) acts as a bidentate ligand bridging two or three metal centers through the N(3) and N(6) donor atoms. The dinuclear derivative *cis*-$[(PMe_3)_2Pt(1\text{-MeCy}(\text{-H}))]_2^{2+}$ appears to be the kinetic product of a condensation reaction between the nucleobase and the hydroxo complex *cis*-$[(PMe_3)_2Pt(\mu\text{-OH})]_2^{2+}$, the species present in the neutral solution of *cis*-$[(PMe_3)_2Pt(NO_3)_2]$, and slowly rearranges into the thermodynamically stable trinuclear derivative *cis*-$[(PMe_3)_2Pt(1\text{-MeCy}(\text{-H}))]_3^{3+}$.

Similarly, the N(9)-substituted adenine (9-R-Ad; R = Me, Et) reacts with *cis*-$[(PMe_3)_2Pt(\mu\text{-OH})]_2^{2+}$, forming the dinuclear complex *cis*-$[(PMe_3)_2Pt(9\text{-R-Ad}(\text{-H}))]_2^{2+}$ with the nucleobase bridging through the N(3) and N(6) atoms as its main product.[7] However, unlike the cytosine analogue, the adenine derivative appears stable, indicating that the formation of polynuclear species has to be the result of a fine combination of electronic and steric factors imposed by the ligands.

We have now investigated the interaction of the model nucleobase 9-methylguanine (9-MeGu) with *cis*-$[(PMe_3)_2Pt(NO_3)_2]$ and *cis*-$[(PMe_3)_2Pt(\mu\text{-OH})]_2(NO_3)_2$, and in this paper we report the characterization of the new complexes *cis*-$[(PMe_3)_2Pt(9\text{-MeGu})_2](NO_3)_2$ and *cis*-$[(PMe_3)_2Pt(9\text{-MeGu}(\text{-H}))]_6(NO_3)_6$. The first belongs to the rich family of N(7)-platinated guanine adducts; the second, containing the hexameric cation *cis*-$[(PMe_3)_2Pt(9\text{-MeGu}(\text{-H}))]_6^{6+}$, represents the first example of cyclic platinum–guanine derivative and a rare example of a hexanuclear platinum complex.[8]

Experimental Section

Materials and Methods. The complexes *cis*-$[(PMe_3)_2Pt(NO_3)_2]$ and *cis*-$[(PMe_3)_2Pt(\mu\text{-OH})]_2(NO_3)_2$ were synthesized as previously reported.[5] The nucleobase 9-MeGu (from Fluka) was used as received.

The ^{1}H and ^{31}P NMR spectra were obtained in D_2O and/or DMSO-d_6 at 298 K in 5 mm sample tubes on a JEOL 90Q spectrometer operating at 89.55 and 36.23 MHz, respectively. The external reference was H_3PO_4 (85% w/w in H_2O) for ^{31}P. ^{1}H chemical shifts are referred to internal TMS or the sodium salt of 3-(trimethylsilyl)-[2,2,3,3-$^2H_4$]-propionic acid.

Synthesis of *cis*-$[(PMe_3)_2Pt(9\text{-MeGu})_2](NO_3)_2$. A 144 mg sample of 9-MeGu (0.873 mmol) was added to a solution of *cis*-$[(PMe_3)_2Pt(NO_3)_2]$ (206 mg, 0.437mmol, in 15 mL of H_2O), and the suspension was stirred at room temperature for 24 h. The resulting solution was filtered to eliminate a trace amount of black solid, the solvent evaporated under vacuum, and the residue dissolved in methanol (50 mL). Addition of diethyl ether afforded a microcrystalline precipitate which was recovered by filtration and dried under vacuum (ca. 10^{-3} Torr, 24 h), obtaining 296 mg of product (yield 84%). Anal. Calc for $C_{18}H_{32}N_{12}O_8P_2Pt$: C, 26.97; H, 4.02; N, 20.97. Found: C, 26.00; H, 3.89; N, 20.36. ^{1}H NMR in DMSO-d_6 at 27 °C (δ, ppm): 11.1 (broad singlet (b s), 1H, N(1)H), 8.10 (s with ^{195}Pt satellites, $^3J_{PtH}$ 15 Hz, 1H, H(8)), 6.9 (b s, 2H, NH_2), 3.50 (s, 3H, N(9)CH_3), 1.54 (doublet (d) with ^{195}Pt satellites, $^2J_{HP}$ 11.05 Hz, $^3J_{HPt}$ 32.2 Hz, 9 H, PMe_3). ^{31}P NMR in DMSO-d_6: δ −28.10, singlet with $^1J_{PPt}$ 3244 Hz.

Table 1. Crystallographic Data for *cis*-$[(PMe_3)_2Pt(9\text{-MeGu})_2](NO_3)_2 \cdot H_2O$ and *cis*-$[(PMe_3)_2Pt(9\text{-MeGu}(\text{-H}))]_6(NO_3)_6 \cdot 18H_2O$

chem formula	$C_{18}H_{34}N_{12}O_9P_2Pt$	$C_{72}H_{180}N_{36}O_{42}P_{12}Pt_6$
fw	819.6	3764.6
cryst system	tetragonal	hexagonal
space group	$P4_12_12$	$R\bar{3}$
$a = b$, Å	11.106(4)	23.178(3)
c, Å	48.89(3)	24.937(3)
V, Å^3	6030(7)	11601(3)
Z	8	3
λ, Å (Mo Kα)	0.710 73	0.710 73
D_{calcd}, g cm^{-3}	1.805	1.616
μ, mm^{-1}	48.3	51.3
I_{max}/I_{min}	1.0/0.78	1.0/0.71
T, °C	21	21
no. of obsd reflns	3655	4547
no. of reflns with $F_o > 3\sigma(F_o)$	3562	2094
residual, %: R, R_w[a]	3.98, 5.02	5.64, 5.97
goodness-of-fit	1.00	0.92

[a] $R = \Sigma|\Delta|/\Sigma|F_o|$; $R_w = (\Sigma w|\Delta|^2/ \Sigma w|F_o|^2)^{1/2}$.

Synthesis of *cis*-$[(PMe_3)_2Pt(9\text{-MeGu}(\text{-H}))]_6(NO_3)_6$. 9-MeGu (89.7 mg, 0.543 mmol) was added to a solution of *cis*-$[(PMe_3)_2Pt(\mu\text{-OH})]_2(NO_3)_2$ (231 mg, 0.272 mmol) in H_2O (7 mL), and the suspension was stirred at room temperature until the nucleobase dissolved (ca. 2 h). A trace amount of platinum was formed which was removed by filtration, and the resulting solution was concentrated to ca. 3 mL, warmed at 60 °C for a few minutes, and left to crystallize at room temperature. In 24 h colorless prisms were formed, which were collected by filtration, washed with ethanol, and dried under vacuum to a constant weight (ca. 10^{-3} Torr, 24 h), obtaining 30 mg of *powdered* material. Anal. Calc for $C_{12}H_{24}N_6O_4P_2Pt$: C, 25.14; H, 4.22; N, 14.66. Found: C, 23.28; H, 4.18; N, 12.28. ^{1}H NMR in DMSO-d_6 (δ, ppm): 8.22 (s with unresolved ^{195}Pt satellites, 1H, H(8)), 6.63 (b s, 2H, NH_2), 3.637 s, 3H, N(9)CH_3, 1.586 (d, $^2J_{PH}$ 11.0 Hz, 9H, PMe_3), 1.488 (d, $^2J_{PH}$ 11.0 Hz, 9H, PMe_3). ^{31}P NMR in DMSO-d_6 (δ = 0, H_3PO_4): AB multiplet with ^{195}Pt satellites at −27.52 ($^1J_{PPt}$ 3112 Hz) and −29.13 ppm ($^1J_{PPt}$ 3258 Hz). From the mother liquor additional amounts of crystals were separated; however, on the basis of the proton and ^{31}P spectra, it was determined that they contained the hexameric complex and a mixture of other unidentified species.

Crystallography. Suitable crystals of the mononuclear complex, analyzing as *cis*-$[(PMe_3)_2Pt(9\text{-MeGu})_2](NO_3)_2 \cdot H_2O$, were obtained by slow concentration of a saturated solution in MeOH. The diffraction data were collected on a colorless spheroidal crystal of diameter *ca.* 0.15 mm, at room temperature, on a Philips PW 1100 four-circle diffractometer, up to $2\theta = 45°$. Suitable crystals of the hexameric complex, analyzing as *cis*-$[(PMe_3)_2Pt(9\text{-MeGu}(\text{-H}))](NO_3) \cdot 3H_2O$, were obtained from H_2O, by the cooling at room temperature of a saturated solution at *ca.* 50 °C. A colorless crystal, with dimensions of 0.50 × 0.12 × 0.20 mm, was rapidly covered with paraffin oil, mounted on a capillary tip, and transferred to the Philips PW 1100 diffractometer. For both structures characteristics of the data collection, processing, and refinement are given in Table 1. Heavy-atom parameters were found from Patterson synthesis, and the non-H atoms were located in subsequent difference Fourier syntheses. For the mononuclear complex, refinement in the alternate space group $P4_32_12$ (No. 96) yielded R = 0.057. As is frequently the case, the nitrate groups and the water molecules in the hexamer are severely disordered and suffering from high thermal motion. Fractional atomic coordinates and thermal isotropic equivalent parameters for both complexes are listed in Table 2, while other information related to data collection and refinement procedure has been deposited as supplementary material. Selected bond distances and angles are presented in Table 3. The SHELXTL-PLUS package of computer programs[9] was employed for the solution and refinement of the structures.

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Table 2. Atomic Coordinates ($\times 10^4$) and Equivalent Isotropic Displacement Coefficients ($Å^2 \times 10^3$)

atom	x	y	z	U[a]
(a) *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu)_2](NO_3)_2{\cdot}H_2O$				
Pt	9513.5(5)	7646.9(4)	9293.6(1)	34(1)
P(1)	8482(4)	8594(4)	8960(1)	42(1)
P(2)	10901(4)	9094(4)	9353(1)	47(1)
N(1A)	5590(12)	7074(12)	9733(3)	53(5)
C(2A)	5004(15)	5996(17)	9694(3)	47(6)
N(3A)	5408(13)	5107(12)	9548(3)	54(5)
C(4A)	6495(14)	5387(16)	9432(3)	49(6)
C(5A)	7181(14)	6395(13)	9463(3)	41(5)
C(6A)	6721(14)	7384(16)	9633(3)	43(5)
N(7A)	8206(10)	6281(10)	9304(3)	51(5)
C(8A)	8197(13)	5199(13)	9193(3)	34(5)
N(9A)	7163(11)	4621(10)	9268(3)	46(4)
N(10A)	3920(11)	5933(14)	9824(3)	70(6)
O(11A)	7194(11)	8330(10)	9676(3)	60(4)
C(12A)	6811(17)	3380(15)	9164(4)	63(7)
N(1B)	11955(12)	3939(11)	9352(3)	44(5)
C(2B)	12220(14)	3463(13)	9598(3)	41(5)
N(3B)	11849(10)	4004(10)	9837(2)	36(4)
C(4B)	11210(13)	5021(13)	9798(3)	34(5)
C(5B)	10953(12)	5545(14)	9553(3)	35(5)
C(6B)	11314(12)	4994(12)	9305(3)	34(5)
N(7B)	10320(11)	6610(10)	9605(3)	36(4)
C(8B)	10191(12)	6676(12)	9868(3)	36(5)
N(9B)	10755(11)	5761(11)	9993(3)	41(4)
N(10B)	12849(12)	2463(12)	9608(3)	50(5)
O(11B)	11145(10)	5347(10)	9073(2)	54(4)
C(12B)	10787(16)	5517(17)	10297(3)	56(6)
C(13)	7221(16)	7680(16)	8843(3)	58(6)
C(14)	7796(16)	10014(14)	9071(4)	62(6)
C(15)	9260(16)	8937(16)	8642(3)	53(6)
C(16)	12417(15)	8468(17)	9505(4)	70(8)
C(17)	10495(21)	9954(16)	9657(5)	82(8)
C(18)	11166(18)	10280(17)	9087(5)	76(8)
N(19)	8511(15)	3228(15)	9801(3)	69(4)
O(20)	7653(16)	2598(16)	9869(3)	109(5)
O(21)	9249(15)	2873(15)	9629(3)	111(5)
O(22)	8541(14)	4275(15)	9890(3)	95(4)
N(23)	14016(15)	2147(16)	8927(4)	74(4)
O(24)	13305(17)	2979(18)	8919(4)	116(6)
O(25)	14094(13)	1521(13)	9131(3)	85(4)
O(26)	14617(17)	1959(14)	8718(4)	113(5)
O(1w)	9608(14)	5798(12)	8588(3)	80(4)
(b) *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu(\text{-}H)]_6(NO_3)_6{\cdot}18H_2O$[b]				
Pt	2212.4(3)	3494.5(3)	1597.9(3)	54.2(3)
P(1)	2477(3)	2883(3)	1062(2)	80(3)
P(2)	1607(3)	2659(3)	2171(2)	82(3)
N(1)	2053(7)	4157(6)	2079(5)	56(7)
C(2)	2457(9)	4501(8)	2490(7)	62(8)
N(2)	2952(7)	4348(8)	2620(7)	79(9)
N(3)	2419(6)	4935(6)	2804(5)	56(6)
C(4)	1884(8)	5004(7)	2629(7)	53(9)
C(5)	1440(7)	4685(7)	2238(6)	45(7)
C(6)	1513(8)	4224(7)	1919(6)	48(8)
O(6)	1135(6)	3898(5)	1556(5)	67(6)
N(7)	1006(6)	4916(6)	2211(5)	52(6)
C(8)	1187(8)	5362(8)	2596(8)	62(8)
N(9)	1730(6)	5446(6)	2876(6)	62(7)
C(9)	2123(9)	5948(9)	3295(8)	79(9)
C(11)	292(2)	334(1)	44(1)	14(2)
C(12)	298(2)	263(2)	141(1)	15(3)
C(13)	186(2)	211(2)	82(2)	12(2)
C(21)	114(2)	281(1)	266(1)	15(2)
C(22)	212(2)	244(3)	254(2)	28(5)
C(23)	104(2)	190(1)	192(1)	22(2)
N(11)[c]	27(3)	544(2)	363(2)	25(4)
O(11)[c]	51(2)	517(1)	407(1)	21(2)
O(12)[c]	76(1)	610(1)	354(1)	17(2)
O(13)[c]	-25(2)	514(2)	331(2)	31(3)
O(1)w[c]	-75(2)	111(2)	186(2)	27(1)
O(2)w[c]	-65(1)	173(1)	89(1)	20(1)
O(3)w[c]	53(1)	292(1)	80(1)	22(2)

[a] Equivalent isotropic *U* defined as one-third of the trace of the orthogonalized $\mathbf{U}_{ij}$ tensors. [b] For the phosphine methyl groups, nitrate, and water molecules atomic coordinates x 10^3 and the isotropic factors $\times 10^2$. [c] Disordered atoms.

Table 3. Selected Bond Lengths (Å) and Angles (deg)

(a) *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu)_2](NO_3)_2{\cdot}H_2O$			
Pt−P(1)	2.255(4)	Pt−P(2)	2.246(5)
Pt−N(7A)	2.10(1)	Pt−N(7B)	2.11(1)
P−C (mean)	1.83(2)		
P(1)−Pt−P(2)	96.2(2)	P(1)−Pt−N(7A)	90.2(4)
P(2)−Pt−N(7A)	171.2(4)	P(1)−Pt−N(7B)	173.4(3)
P(2)−Pt−N(7B)	90.4(3)	N(7A)−Pt−N(7B)	83.2(5)
Pt−N(7A)−C(5A)	121(1)	Pt−N(7A)−C(8A)	131(1)
Pt−N(7B)−C(5B)	121(1)	Pt−N(7B)−C(8B)	130(1)
(b) *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu(\text{-}H)]_6(NO_3)_6{\cdot}18H_2O$			
Pt−P(1)	2.246(7)	Pt−P(2)	2.245(5)
Pt−N(1)	2.12(2)	Pt−N(7)'	2.09(1)
P−C(mean)	1.78(4)		
P(1)−Pt−P(2)	94.9(2)	P(1)−Pt−N(7)′	91.5(4)
P(2)−Pt−N(7)′	173.6(4)	P(1)−Pt−N(1)	174.3(4)
P(2)−Pt−N(1)	90.2(4)	N(1)−Pt−N(7)′	83.4(5)
Pt−N(7)′−C(5)	131(1)	Pt−N(7)′−C(8)	124(1)
Pt−N(1)−C(2)	123(1)	Pt−N(1)−C(6)	114(1)

Results and Discussion

Characterization of the Mononuclear Complex *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu)_2](NO_3)_2{\cdot}H_2O$. The addition of 1 equiv of *N*(*9*)-MeGu to a solution of *cis*-$[(PMe_3)_2Pt(NO_3)_2]$, *ca.* 0.1 M in D_2O, determines the dissolution of the nucleobase in ca. 2 h at room temperature. The ^{31}P NMR spectrum of the resulting solution shows a complex pattern of resonances in the range −23.7 to −29.7 ppm flanked by ^{195}Pt satellites. The further addition of a second equivalent of nucleobase causes the appearance of an exceedingly simple pattern, *i.e.* a sharp singlet at δ −29.03 flanked by the ^{195}Pt satellites ($^1J_{PtP}$ 3268 Hz). The presence at this stage of chemically equivalent phosphine ligands is consistent with identical chemical environments for the two coordinated nucleobases. The protonic spectrum, in fact, exhibits a single set of resonances for both the H(8) and NCH_3 guanine protons. Moreover, the occurrence of ^{195}Pt satellites (J_{PtH} 15 Hz) flanking the singlet at δ 8.03, attributable to the H(8) resonance, is a clear indication of coordination of the nucleobase at the N(7) position.[10] Accordingly, the guanine N(1)H resonance, undetectable in D_2O, is clearly observable in DMSO-d_6 solution in which it occurs as a broad singlet at δ 11.1 (see Experimental Section), 0.6 ppm at a lower field with respect to the value found for the free base. As frequently observed, the metal binding determines a shift to a lower field of all the nucleobase resonances also in this case, in particular for the protons directly bonded to the purine ring.

The N(7)-coordination of the nucleobase was conclusively established in the solid state by a single-crystal X-ray analysis. The compound crystallizes from methanol as the monohydrate, in the tetragonal system, space group $P4_12_12$. The structure consists of a discrete, essentially square planar *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu)_2]^{2+}$ cation (Figure 1), in which the two guanine ligands, designated A and B, are bonded through the N(7) atom, with the purine rings oriented in a head-to-tail conformation.

In Table 3 the bond distances and angles observed in this complex are collected. The planes containing the purine rings form a dihedral angle of 77.6° and are inclined at 83.6 and 101.7°, respectively, to the plane defined by the P_2N_2 donor atom set. The platinum atom is significantly displaced from the mean plane of ring B (0.19 Å) while it devictes by only 0.01 Å from ring A.

The nitrate anions and the water molecule are involved in an extensive hydrogen bond framework as shown in Figure 2. In

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[10] Lippert, B. *Prog. Inorg. Chem.* **1989**, *37*, 1.

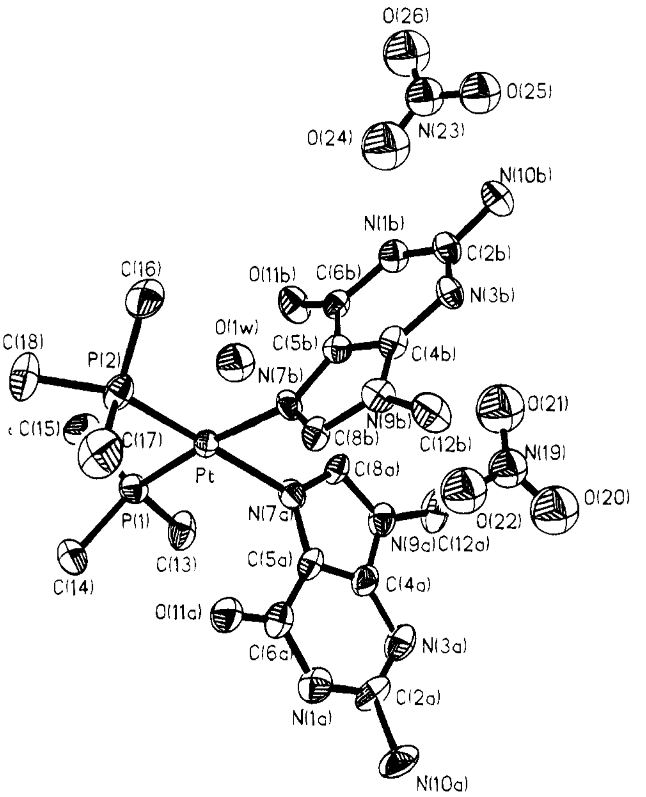

Figure 1. Overall view of the *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu)_2](NO_3)_2{\cdot}H_2O$ complex showing the atom-numbering scheme. The atoms are drawn at 50% probability contours of thermal motion.

particular, a nitrate group interacts with the hydrogen atoms of the guanine NH_2 and the N(1)H groups (*e.g.* N(10b)$\cdots$O(25) = 2.90 Å and N(1b)$\cdots$O(24) 2.80 Å, respectively), whereas the water molecule interacts with the oxygen atom of the oxopurine ring (O(1w)$\cdots$O(11b) = 2.96Å) and the remaining NO_3^- ion (O(1w)$\cdots$O(25) = 2.85 Å) (Table 4).

The Pt−P and Pt−N bond distances and angles are in good agreement with the average values found in related complexes of platinum(II) stabilized by trialkylphosphines. As an example, in the cytosine analog *cis*-$[(PMe_3)_2Pt(1\text{-}MeCy)_2]^{2+}$ containing two N(3)-bonded 1-MeCy molecules in a head-to-tail conformation, the Pt−P and Pt−N bond distances are 2.256(5), 2.254(5) and 2.092(9), 2.108(9) Å, respectively.[5] In this case the presence of strong intraligand hydrogen bonds imposes quite a large dihedral angle between the nucleobase rings (94.2(3)°). In the isocaffeine complex *cis*-$[(PEt_3)_2Pt(\text{isocaffeine})_2]^{2+}$, where hydrogen bonding cannot occur, the dihedral angle between the rings is remarkably reduced (65.4°).[11]

The structure of the mononuclear complex *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu)_2]^{2+}$ establishes a further example of platinum(II) containing two N(7)-coordinated 6-oxopurine ligands in which the two nucleobases are in a head-to-tail arrangement, the conformation energetically more favorable, in absence of intraligand hydrogen bonding.[12] In the amino analog *cis*-$[(NH_3)_2Pt(9\text{-}EtGu)_2]^{2+}$ the 9-ethylguanine moieties present a head-to-head conformation imposed by a hydrogen bond interaction between the oxygen of the oxopurine ring and the ancillary ligands.[1c,d]

Characterization of the Hexanuclear Complex *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu(\text{-}H))]_6(NO_3)_6{\cdot}18H_2O$. When the nucleobase 9-MeGu is added to a neutralized solution of *cis*-$[(PMe_3)_2Pt(NO_3)_2]$ in D_2O, ca. 0.1 M, a complex reaction mixture is formed. In ca. 2 h at room temperature the nucleobase dissolves and the ^{31}P NMR spectrum of the resulting solution, obtained after 4 h at room temperature, indicates the complete disappearance of the hydroxo complex *cis*-$[(PMe_3)_2Pt(\mu\text{-}OH)]_2^{2+}$, the only species detectable in the solution of *cis*-$[(PMe_3)_2Pt(NO_3)_2]$ at pH 7. Its sharp singlet, at δ −25.58, is in fact replaced by a broad and composite signal in the range −27.8 to −29.7 ppm with the pertinent ^{195}Pt satellites, and these spectral features do not change significantly after several days. Similar results are obtained when the nucleobase is reacted, in molar ratio 2:1, directly with *cis*-$[(PMe_3)_2Pt(\mu\text{-}OH)]_2(NO_3)_2$. The slow evaporation of the reaction mixture at room temperature leads to the separation of a first crop of colorless crystals (yield ca. 10%) whose elemental analysis is consistent with the composition $[(PMe_3)_2Pt(9\text{-}MeGu(\text{-}H))](NO_3){\cdot}nH_2O$, with n in the range 2−3. The ^1H NMR spectrum of the isolated product in DMSO-d_6 exhibits all the nucleobase resonances shifted downfield relative to those of the free ligand but lacks that attributable to the N(1)H proton. In particular, the H(8) resonance is observed as a singlet, with unresolved platinum satellites, at δ 8.217, shifted 0.62 ppm with respect to the uncoordinated nucleobase. The phosphine methyl protons exhibit two equally intense doublets ($^2J_{PH}$ 11.0 Hz) centered at δ 1.586 and 1.488, with unresolved ^{195}Pt satellites, indicating chemically inequivalent PMe_3 ligands. Accordingly, the ^{31}P NMR spectrum shows an AB multiplet as the major resonance, flanked by ^{195}Pt satellites, centered at δ −27.52 ($^1J_{PtP}$ 3112 Hz) and −29.13 ($^1J_{PtP}$ 3258 Hz), respectively, with $^2J_{P(A)P(B)}$ = 24.4 Hz. The values of coupling constants are very similar to those found in related compounds having the *cis*-$(PMe_3)_2Pt$ unit linked to nitrogen atoms of neutral and/or deprotonated cytosine[6] or adenine[7] ligands.

The actual binding mode of the nucleobase has been established, in the solid state, by a single-crystal X-ray analysis. Figure 3 illustrates the molecular structure and the labeling scheme of the cationic complex.

The compound obtained from an aqueous solution crystallizes in the hexagonal system, space group $R\bar{3}$, and contains the hexameric cation *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu(\text{-}H))]_6^{6+}$ in which six *cis*-$(PMe_3)_2Pt$ units are symmetrically bridged by the guanine ligands through their N(1) and N(7) atoms. The resulting cycle has approximate S_3 symmetry, the oxopurine rings being alternatively disposed above and below the planes passing through the metal atoms as schematically depicted in Figure 4.

The platinum atoms lie in two parallel planes separated by 0.34 Å from each other, and these planes make an angle of 50° with the plane of the nucleobases. The distance between two adjacent metal atoms is 6.5 Å, and the longest Pt$\cdots$Pt distance is 12.9 Å.

Each platinum atom is in a distorted square-planar arrangement in which the donor atoms are (i) the phosphorus atoms of two trimethylphosphines [(Pt−P = 2.245(7) Å (average); P−Pt−P = 94.9(2)°], (ii) the N(1) [Pt−N(1) = 2.12(2) Å], and (iii) the N(7)′[Pt−N(7)′ = 2.09(1) Å] atoms, respectively, of two anionic 9-MeGu(-H) ligands. The metal-bonded nitrogen atoms of the two adjacent bases form an angle [N(1)−Pt−N(7)′] of 83.4(5)°. The nucleobases are strictly planar, and the bond distances and angles within the ring compare well with those found in the related mononuclear complex.

The cationic oligomer is surrounded by the water molecules and the nitrate anions. The latter are characterized by high standard deviations in bond lengths and angles, suggesting that they are partially disordered. Hydrogen bonding plays an

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(11) Bushnell, G. W.; Densmore, J. R.; Dixon, K. R.; Ralfs, A. C. *Can. J. Chem.* **1983**, *61*, 1132.

(12) Hambley, T. W. *Inorg. Chem.* **1988**, *27*, 1073.

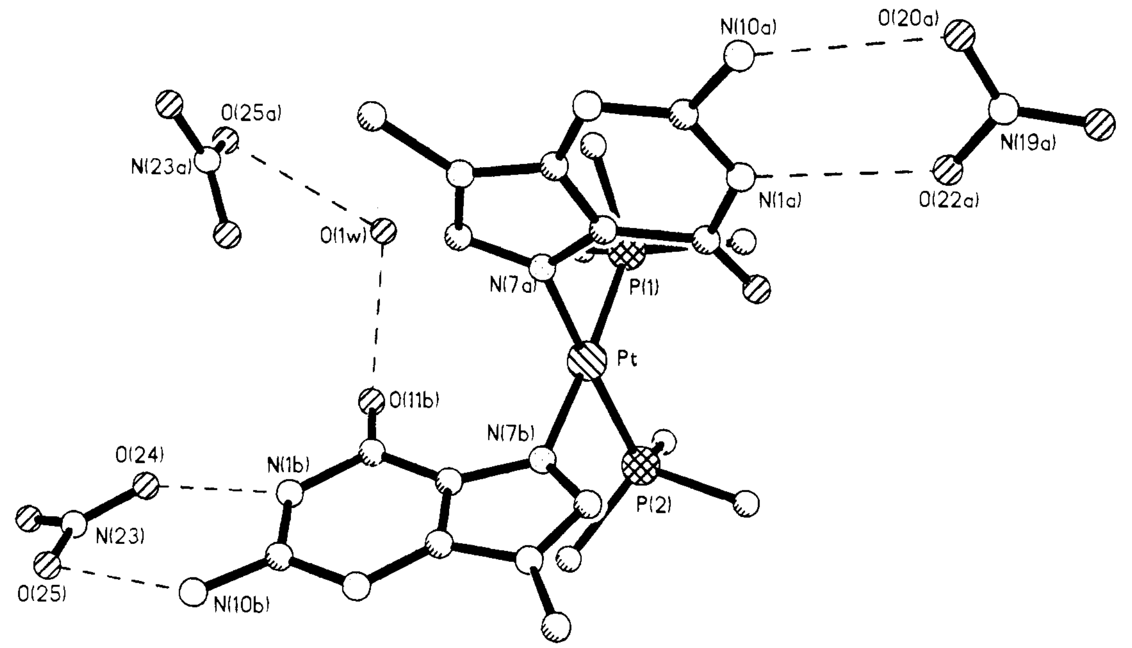

Figure 2. Hydrogen bond motif in *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu)_2](NO_3)_2 \cdot H_2O$.

Table 4. Possible Hydrogen Bonds and Selected Contact Distances (Å)

(a) *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu)_2](NO_3)_2 \cdot H_2O$			
N(1B)···O(24)	2.80	P(1)···P(2)	3.35
N(10B)···(25)	2.90	P(1)···N(7A)	3.09
O(11B)···O(1w)	2.96	N(7A)···N(7B)	2.79
O(1)w···O(25a)[a]	2.85	P(2)···N(7B)	3.09
N(10A)···O(20a)[b]	2.84	Pt···O(11A)	3.27
N(1A)···O(22a)[b]	2.86	Pt···O(11B)	3.31
		Pt···O(1w)	4.02
(b) *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu(\text{-}H)]_6(NO_3)_6 \cdot 18H_2O$			
O(1)w···O(2)w	2.76	P(1)···P(2)	3.31
O(2)w···O(3)w	2.75	P(1)···N(7)′	3.11
O(3)w···O(6)	2.73	N(1)···N(7)′	2.80
O(1)w···O(11)[c]	2.74	P(2)···N(1)	3.10
N(2)···O(6)[d]	2.96	Pt···O(6)	3.07
O(3)w···O(13)[d]	2.50		

[a] At $x - {}^1/_2, {}^1/_2 - y, {}^7/_4 - z$. [b] At $y, x, 2 - z$. [c] At $y - {}^2/_3, -x + y - {}^1/_3, {}^2/_3 - z$. [d] At $x - y + {}^2/_3, {}^1/_3 + x, {}^1/_3 - z$.

important role in stabilizing both the hexanuclear cation and the crystal lattice, which, in fact, is destroyed in the absence of the mother liquor. An intramolecular hydrogen bond interaction occurs between the hydrogen atoms of the exocyclic NH_2 group and the oxygen atoms of two adjacent nucleobases (O(6)···N-(2) = 2.96 Å; N-H···O = 146°). Moreover, the water molecules interact with the nitrate ions in a complex network, only partially defined owing to the high thermal motion displayed by these groups.

Conclusions

As previously reported for the model nucleobases cytosine and adenine, N(9)-substituted guanine forms with the trimethylphosphine complex *cis*-$[(PMe_3)_2Pt(NO_3)_2]$ a stable bisadduct, *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu)_2]^{2+}$, when the reaction is carried out at autogenous pH where the predominant species is *cis*-$[(PMe_3)_2Pt(H_2O)_2]^{2+}$. In neutral solution the aquo complex is converted into the dinuclear species *cis*-$[(PMe_3)_2Pt(\mu\text{-}OH)]_2^{2+}$ and the interaction of the nucleobase with the nitrato complex at pH 7 can be described as a condensation reaction between the coordinated hydroxide ion and the guanine N(1)H hydrogen. Spectroscopic evidence indicates the presence in solution of a complex mixture of products, probably a variety of oligomers of general formula *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu(\text{-}H))]_n^{n+}$, from which the cyclic hexamer ($n = 6$) crystallizes as a pure compound

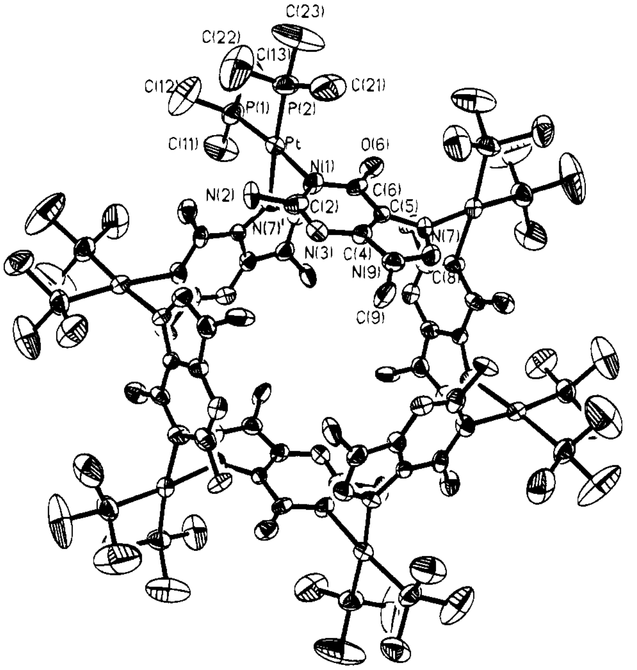

Figure 3. Overall view of the cation *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu(\text{-}H))]_6^{6+}$ with the labeling scheme. Nitrate groups and water molecules have been omitted for clarity.

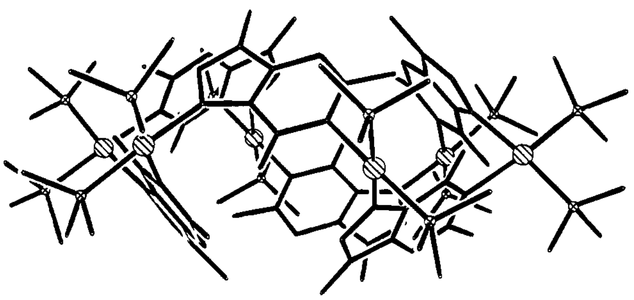

Figure 4. Side view of the cation *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu(\text{-}H))]_6^{6+}$.

(>95% on the basis of its ^1H and ^{31}P NMR spectra) in the first fractions of the crystallized solid. The subsequent fractions contain increasing amounts of other species as indicated by the presence of numerous resonances in addition to those due to the hexamer. Once formed, the hexacation *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu(\text{-}H))]_6^{6+}$ appears stable, its ^1H and ^{31}P NMR spectra in D_2O being unchanged after several months.

Whereas the characterization of cyclic complexes of the guanine has no precedent, a hexanuclear complex of platinum(IV) containing the theophylline anion has been structurally characterized.[8]

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Supplementary Material Available: Tables of complete crystallographic data, bond lengths and angles, and anisotropic thermal parameters for *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu)_2](NO_3)_2\cdot H_2O$ and *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu(\text{-}H))]_6(NO_3)_6\cdot 18H_2O$ and a figure showing the packing diagram of *cis*-$[(PMe_3)_2Pt(9\text{-}MeGu(\text{-}H))]_6(NO_3)_6\cdot 18\ H_2O$ (7 pages). Ordering information is given on any current masthead page.

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