Reaction of Model Nucleobases with the Diaqua(bis(*N*-methylimidazol-2-yl) ketone)platinum(II) Dication. Synthesis and Structure of the Head-to-Tail Isomers of Bis(9-methylguanine-N^7)(bis(*N*-methylimidazol-2-yl) ketone)platinum(II) Perchlorate, Bis(1-methylcytosine-N^3)(bis(*N*-methylimidazol-2-yl) ketone)platinum(II) Perchlorate, Bis(μ-1-methylthyminato-N^3,O^4)bis[(bis(*N*-methylimidazol-2-yl) ketone)platinum(II)] Perchlorate, and Bis(μ-1-methyluracilato-N^3,O^4)bis[(bis(*N*-methylimidazol-2-yl) ketone)platinum(II)] Nitrate

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The reactions of $[Pt(bmik)(H_2O)_2]^{2+}$ (bmik = bis(*N*-methylimidazol-2-yl) ketone) with 9-methylguanine (9-MeGH), 1-methylcytosine (1-MeC), 1-methylthymine (1-MeTH), and 1-methyluracil (1-MeUH) were studied, and the products were characterized by X-ray structure analysis. The bmik diaqua complex reacts to mononuclear complexes with the bases 9-methylguanine and 1-methylcytosine like its *cis*-dichlorodiammineplatinum(II) (*cis*-DDP) analog. In contrast, it forms dinuclear ones with 1-methylthymine and 1-methyluracil. In the structure of $[Pt(bmik)(9\text{-}MeGH)_2](ClO_4)_2 \cdot 2H_2O$ (**1**, $PtC_{21}H_{24}N_{14}O_{11}Cl_2 \cdot 2H_2O$, monoclinic, $P2_1/c$, with cell dimensions of a = 8.345(2) Å, b = 29.800(5) Å, c = 13.232(3) Å, β = 93.69(2)°, Z = 4, and V = 3284(1) Å^3) the platinum atom is coordinated by a bmik ligand and two 9-methylguanines via their N(7) nitrogen atoms. The two nucleobases are arranged head-to-tail as in the molecular cation of $[Pt(bmik)(1\text{-}MeC)_2](ClO_4)_2 \cdot 1.5H_2O$ (**2**, $PtC_{19}H_{24}N_{10}O_{11}Cl_2 \cdot 1.5H_2O$, triclinic, $P\bar{1}$, with cell dimensions of a = 7.507(2) Å, b = 12.483(3) Å, c = 17.177(5) Å, α = 109.26(2)°, β = 93.15(2)°, γ = 99.64(2)°, Z = 2, and V = 1488(1) Å^3). The metal atom is coordinated by the N(3) atom, and the head-to-tail arrangement of the 1-methylcytosine bases is stabilized by hydrogen bonds. A formation of dinuclear complexes was not observed. Dinuclear cations can be synthesized with 1-methylthymine and 1-methyluracil as nucleic acid model nucleobases: $[Pt_2(bmik)_2(1\text{-}MeT)_2](ClO_4)_2 \cdot 5H_2O$ (**3**, $Pt_2C_{30}H_{34}N_{12}O_{14}Cl_2 \cdot 5H_2O$, triclinic, $P\bar{1}$, with a = 12.258(3) Å, b = 13.491(3) Å, c = 15.332(3) Å, α = 78.04(2)°, β = 68.83(2)°, γ = 68.48(2)°, Z = 2, and V = 2192(1) Å^3) and $[Pt_2(bmik)_2(1\text{-}MeU)_2](NO_3)_2 \cdot 2H_2O$ (**4**, $Pt_2C_{28}H_{30}N_{14}O_{12} \cdot 2H_2O$, orthorhombic, *Pbcn*, with a = 13.877(4) Å, b = 11.884(3) Å, c = 21.970(5) Å, Z = 4, and V = 3622(1) Å^3). The intramolecular Pt···Pt distances are 2.900(1) (**3**) and 2.841(1) Å (**4**). Both bases show a head-to-tail arrangement while the platinum atoms are coordinated by two additional bmik ligands. Oxidation of **2** and **3** to platinum blues with higher valent Pt was not observed, presumably because of the competing oxidation of the low-potential bmik ligand. This different redox behavior distinguishes the reaction properties of *cis*-DDP and $Pt(bmik)Cl_2$ with nucleobases in a characteristic way. ^1H NMR data are reported for the complexes.

Introduction

In a series of investigations we have studied the synthesis and chemical properties of platinum complexes with a bis(*N*-methylimidazol-2-yl) ketone (bmik) ligand and 9-methylguanine, 1-methylcytosine, 1-methylthymine, and 1-methyluracil (Figure 1) as possible models for platinum–DNA interactions. In addition to the coordination properties of the novel class of bis(imidazole) ligands, the multisite coordination properties of the pyrimidine nucleobases have been of continuous interest to us for some time. The report of a class of intensely colored Pt antitumor compounds by Rosenberg's group in 1975 initiated wide interest in these compounds. They are derived from *cis*-$[(NH_3)_2Pt(H_2O)_2]^{2+}$ and uracil, thymine, or related ligands.[1] These complexes are interesting both for their biological effects and their intriguing chemistry.[2]

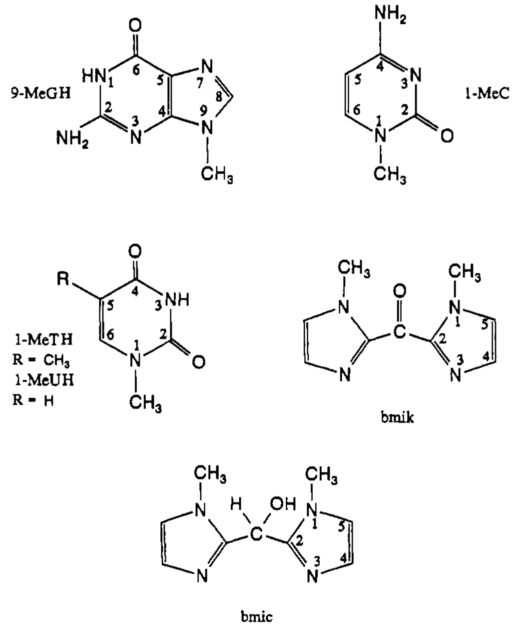

Figure 1. bmik, bmic, 9-methylguanine, 1-methylcytosine, 1-methylthymine, and 1-methyluracil ligands.

The *cis*-dichloroplatinum complex of the bmik ligand mentioned above is the prototype of a new and interesting generation of antitumor agents with tertiary amine ligands.[3] Their activity is especially remarkable, since the tertiary amines such as bmik do not form hydrogen bonds to DNA constituents. Hydrogen bonds of this kind are considered to be essential for antitumor activity.[4–6] A study of the reaction behavior of $Pt(bmik)Cl_2$ toward nucleobases in comparison to that of its *cis*-DDP analog appeared to be very interesting. A similar platinum complex, bis((*N*-

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methylimidazol-2-yl)carbinol)dichloroplatinum(II), [Pt(bmic)Cl_2], shows considerable cytostatic activity similar to *cis*-diammineplatinum(II) but with much lower toxicity.[3] The ligand is shown in Figure 1. For the present investigations an analogous ligand was chosen. The platinum complex of this ligand does not reach the same high cytostatic activity as the carbinol derivative, but the reaction products with the model nucleobases show a much higher crystallization tendency. The reaction of metal compounds with DNA may be modeled at various stages of complexity. In our case the deoxyribose moiety is replaced by an alkyl group in order to prevent metal coordination at the N(1) (py nucleobase) or N(9) site (pu nucleobase) (Figure 1). Typically, model bases used in this work are 9-methylguanine (9-MeGH), 1-methylcytosine (1-MeC), 1-methylthymine (1-MeTH), or its RNA analog 1-methyluracil (1-MeUH) (Figure 1). As part of a program aimed at the systematic synthesis of reaction products between Pt(bmik)Cl_2 and the model nucleobases and their investigation by X-ray structure analysis and spectroscopic techniques, we have isolated, among others,[3,7,8], the four complexes [Pt(bmik)(9-MeGH)$_2$]$(ClO_4)_2\cdot 2H_2O$ (**1**), [Pt(bmik)(1-MeC)$_2$]$(ClO_4)_2\cdot 1.5H_2O$ (**2**), [Pt_2(bmik)$_2$(1-MeT)$_2$]$(ClO_4)_2\cdot 5H_2O$ (**3**), and [Pt_2(bmik)$_2$(1-MeU)$_2$]$(NO_3)_2\cdot 2H_2O$ (**4**).

Experimental Section

Preparation of Compounds. The starting material, Pt(bmik)Cl_2, was prepared from $K_2[PtCl_4]$ by the following method: A solution of 0.415 g (1 mmol) of $K_2[PtCl_4]$ in 25 mL of water was heated to 40 °C under constant stirring and dropwise addition of a solution of 0.190 g of bis(*N*-methylimidazol-2-yl) ketone (prepared by a method of Canty et al.[9]) in 25 mL of water. The mixture was stirred for an additional 2 h at 40 °C and then cooled to 0 °C. The resulting Pt(bmik)Cl_2 was removed by filtration and washed three times with 100 mL of warm water. The yield was 0.374 g (82%) after drying.

Compounds **1–4** were obtained from the reaction of [Pt(bmik)$(H_2O)_2$]$^{2+}$ with the methylated nucleobases as follows: An aqueous solution of [Pt(bmik)$(H_2O)_2$]$^{2+}$ was prepared by adding 0.170 g (1 mmol) of $AgNO_3$ to a suspension of 0.228 g (0.5 mmol) of Pt(bmik)Cl_2 in 10 mL of water. After the suspension had been stirred for 2 h at 50 °C, the temperature was lowered to room temperature and the resulting AgCl precipitate was removed by centrifugation. A solution of 116 mg (0.7 mmol) of 9-methylguanine, 88 mg (0.7 mmol) of 1-methylcytosine, 49 mg (0.35 mmol) of 1-methylthymine, or 44 mg (0.35 mmol) of 1-methyluracil in 10 mL of water was added in each case to the centrifugate. The solutions were kept at 40 °C for 20 h. After that 5–10 drops of a solution of $NaClO_4$ (0.5 m) in water were added to the warm solutions. After being cooled to room temperature, the filtered solution was allowed to evaporate in air.

Bis(9-methylguanine-*N*^{7})(bis(*N*-methylimidazol-2-yl) ketone)platinum(II) Perchlorate (1): Head-to-Tail Isomer. Yellow compact, polyhedral crystals of **1** were collected. A second batch was obtained from further evaporation of the filtrate, providing a total yield of 20%. Anal. Calcd for $PtC_{21}H_{24}N_{14}O_{11}Cl_2\cdot 2H_2O$ (**1**): C, 26.54; H, 2.97; N, 20.63. Found: C, 26.48; H, 2.99; N, 20.24.

Bis(1-methylcytosine-*N*^{3})(bis(*N*-methylimidazol-2-yl) ketone)platinum(II) Perchlorate (2): Head-to-Tail Isomer. Yellow rod-shaped crystals of **2** were collected. A second batch was obtained from further evaporation of the filtrate, providing a total yield of 19%. Anal. Calcd for $PtC_{19}H_{24}N_{10}O_{11}Cl_2\cdot 1.5H_2O$ (**2**): C, 26.49; H, 3.16; N, 16.26. Found: C, 25.71; H, 3.19; N, 16.63.

Bis(μ-methylthyminato-*N*^{3},*O*^{4})bis[(bis(*N*-methylimidazol-2-yl) ketone)platinum(II)] Perchlorate (3): Head-to-Tail Isomer. Red plate-shaped crystals of **3** were collected. A second batch was obtained from further evaporation of the filtrate, providing a total yield of 21%. Anal. Calcd for $Pt_2C_{30}H_{30}N_{12}O_{14}Cl_2\cdot 5H_2O$ (**3**): C, 26.93; H, 3.32; N, 12.57. Found: C, 26.78; H, 3.28; N, 12.23.

Bis(μ-methyluracilato-*N*^{3},*O*^{4})bis[(bis(*N*-methylimidazol-2-yl) ketone)platinum(II)]Nitrate (4): Head-to-Tail Isomer. Red compact, polyhedral crystals of **4** were collected. A second batch was obtained from further evaporation of the filtrate, providing a total yield of 15%. Anal. Calcd for $Pt_2C_{28}H_{34}N_{14}O_{12}\cdot 2H_2O$ (**4**): C, 28.48; H, 2.90; N, 16.61. Found: C, 28.13; H, 3.01; N, 16.45.

The rather low yields for **1–4** refer to the highly pure first fractions of the very soluble products. Higher yields can be obtained on further evaporation, however, at the cost of contamination by decomposition and/or rearrangement products such as [Pt(bmik)$_2$]$^{2+}$.

Physical Measurements. ^1H NMR spectra were obtained on a Bruker instrument at 300 MHz. D_2O solutions were prepared at 50 °C and studied at 25 °C. Chemical shift data are reported relative to TMS.

Collection and Reduction of X-ray Data. Single-crystal X-ray diffraction data were measured on a Syntex-P2$_1$ or a Siemens-R3 four-circle diffractometer using graphite-monochromated Mo Kα radiation. Unit cell parameters were obtained from a least-squares fit of 25 reflections of high 2Θ angle. The details of the data collection are given in Table 1. Two standard reflections were measured after every 100 measurements during the data collection. Lorentz and polarization corrections were applied to the data. Empirical absorption corrections based on ψ-scan data were also applied. For each of the structures intensity data for 8–12 reflections were recorded during a full turn around the diffraction vectors, and relative transmissions were calculated.[10]

Structure Solution and Refinement. The structures were solved by the usual direct methods and/or Patterson and Fourier methods[10] and refined on F^2 with anisotropic thermal parameters for all non-hydrogen atoms.[11] Space group determinations were unambiguous from the systematically absent reflections and from intensity statistics in the cases of **2–4**. Neutral-atom scattering factors and anomalous dispersion corrections for all non-hydrogen atoms were obtained from ref 12, and hydrogen atom scattering factors from ref 13. The positions of all hydrogen atoms were placed at calculated positions (d(C–H) = 0.95 Å) and constrained to "ride" on the carbon atoms to which they are attached. The N–H hydrogen atoms were observed in difference Fourier maps, but their positions were calculated (d(N–H) = 0.86 Å) and constrained, assigned on the basis of reasonable geometry. More details of the refinements are given in Table 1.

^{1}H NMR Studies. Table 2 contains the chemical shift data for this series of complexes. Protons of the bmik ligand and the nucleobases were readily assigned by comparison with free bmik and the free model nucleobases.[14] All compounds show doublet peaks of the aromatic protons (4-H and 5-H, Figure 1) of the bis(*N*-methylimidazol-2-yl) ketone ligand around 7 and 7.5 ppm that are shifted to lower field in comparison to the free ligand. The resonances of the N–CH_3 groups of the bmik ligand and the *N*-methylated nucleobases are observed between 3.5 and 4.2 ppm. The aromatic proton (8-H) of the coordinated methylguanine is found at 8.21 ppm and is shifted about 0.5 ppm to lower field as a result of the coordination of the metal atom. The complexes with pyrimidine bases show resonances of the aromatic protons (5′-H and 6-H) at about 6.1 and 7.8 ppm, and the methyl resonance of the methylthymine can be found at 1.9 ppm, being slightly shifted to lower field in comparison to the free bases. As a result of the molecular C_2 symmetry of the head-to-tail arrangement of the nucleobases, a splitting of 0.1 ppm of the aromatic ligand resonances of the dinuclear complexes can be found because of the nonequivalence of the protons of the two imidazole rings in the bmik ligand.

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Table 1. Crystallographic Data for **1**–**4**

	1	**2**	**3**	**4**
formula	$PtC_{21}H_{24}N_{14}O_{11}Cl_2 \cdot 2H_2O$	$PtC_{19}H_{24}N_{10}O_{11}Cl_2 \cdot 1.5H_2O$	$Pt_2C_{30}H_{34}N_{12}O_{14}Cl_2 \cdot 5H_2O$	$Pt_2C_{28}H_{30}N_{14}O_{12} \cdot 2H_2O$
fw	950.55	861.50	1337.85	1180.87
system	monoclinic	triclinic	triclinic	orthorhombic
space group	$P2_1/c$	$P\bar{1}$	$P\bar{1}$	*Pbcn*
a, Å	8.345(2)	7.507(2)	12.258(3)	13.877(4)
b, Å	29.800(5)	12.483(3)	13.491(3)	11.884(3)
c, Å	13.232(3)	17.177(5)	15.332(3)	21.970(5)
α, deg		109.26(2)	78.04(2)	
β, deg	93.69(2)	93.15(2)	68.83(2)	
γ, deg		99.64(2)	68.48(2)	
V, Å^3	3283.7	1487.8	2191.7	3622.1
Z	4	2	2	4
T, K	170	293	170	170
d_{calc}, g cm^{-3}	1.919	1.923	2.028	2.165
cryst size, mm	0.10 × 0.22 × 0.12	0.05 × 0.02 × 0.23	0.18 × 0.16 × 0.03	0.18 × 0.15 × 0.23
μ, mm^{-1}	4.52	4.97	6.67	7.81
abs corr	ψ-scan	ψ-scan	ψ-scan	ψ-scan
transm factor	0.38–0.54	0.73–0.81	0.28–0.73	0.21–0.43
index ranges	$0 \le h \le 10$	$0 \le h \le 8$	$0 \le h \le 15$	$0 \le h \le 17$
	$0 \le k \le 36$	$-14 \le k \le 14$	$-16 \le k \le 17$	$0 \le k \le 15$
	$-16 \le l \le 16$	$-19 \le l \le 19$	$-18 \le l \le 19$	$0 \le l \le 28$
θ range	2.54–26.05°	2.50–24.05°	2.70–27.40°	2.37–27.06°
radiation (λ, Å)	Mo Kα (0.710 73)	Mo Kα (0.710 73)	Mo Kα (0.710 73)	Mo Kα (0.710 73)
no. of reflns collcd	6930	5115	10225	3980
no. of indep reflns	6476	4711	9630	3979
R_{int}[a]	0.034	0.041	0.031	
no. of obs reflns [$I > 2\sigma(I)$]	4751	4049	7085	2953
GOOF	1.062	1.120	1.036	1.061
R[b]	0.042	0.060	0.051	0.033
R_w[c]	0.080	0.146	0.175	0.064
a	0.0332	0.0811	0.0755	0.0294
b	7.46	14.15	23.17	4.24

[a] $R_{int} = \sum|F_o^2 - F_o^2(\text{mean})|/\sum[F_o^2]$. [b] $R = \sum||F_o| - |F_c||/\sum|F_o|$. [c] $R_w = [\sum w(F_o^2 - F_c^2)^2/\sum w(F_o^2)^2]^{1/2}$. [d] $w = 1/[\sigma^2(F_o^2) + (aP)^2 + bP]$, where $P = (\max(F_o^2 \text{ or } 0) + 2F_c^2)/3$.

Table 2. ^{1}H-Chemical Shifts (ppm) of **1**–**4**

	5′-H	6-H	C–CH$_3$	8-H	N–CH$_3$′	4-H	5-H	N–CH$_3$
1				8.21 (s)	3.56 (s)	7.46 (d)	6.44 (d)	4.06 (s)
2	6.11 (d)	7.72 (d)			3.46 (s)	7.61 (d)	6.86 (d)	4.17 (s)
3		7.78 (s)	1.89 (s)		3.48 (s)	7.51; 7.59 (d)	6.86; 6.98 (d)	4.18; 4.27 (s)
4	6.25 (d)	7.79 (d)			6.25 (s)	7.55; 7.61 (d)	6.78; 6.86 (d)	4.06; 4.17 (s)

Results and Discussion

[Pt(bmik)(9-MeGH)$_2$](ClO$_4$)$_2$·2H$_2$O. The phenomenon of preferential binding of *cis*-[a$_2$PtCl$_2$] (a = amine function) to guanine was recognized at an early stage.[1,15] The preference of *cis*-DDP or its analog for the guanine N(7) site is generally preserved in oligonucleotides containing adjacent guanines or two guanines with another base separating the two.[16–20] As a simple model compound for our new antitumor-active complexes binding to GG in the DNA, we synthesized [Pt(bmik)(9-MeGH)$_2$](ClO$_4$)$_2$·2H$_2$O and determined its structure by X-ray diffraction analysis.

The unit cell parameters, space group, and other experimental details of the X-ray diffraction study are summarized in Table 1. The final atomic positional parameters together with their estimated standard deviations are reported in Table 3. Selected distances and angles with estimated standard deviations for **1** are presented in Table 4. One of the two perchlorate anions in the structure of **1** is disordered around the Cl(2) atom. Two positions for the oxygen atoms of the ClO$_4^-$ tetrahedron with occupation factors of 0.65 and 0.35 were refined without any restraints.

The compound **1** crystallizes with four [Pt(bmik)(9-MeGH)$_2$]$^{2+}$ cations per unit cell. Each platinum atom is coordinated in a square-planar arrangement by a bmik ligand and two 9-methylguanines via their N(7) nitrogen atoms as reported in all complexes of platinum with N(9)-blocked guanine residues so far.[1,21] The molecular cation is shown in Figure 2.

The distance between the N(7) atoms of the two bases is 2.81 Å. The bases are almost planar and head-to-tail oriented. The dihedral angle between the two metal-bonded purine ligands is large (89°) and indicates that there is little or no intracomplex base–base interaction.

Both 9-methylguanine rings show large dihedral angles between the purine ligand and the platinum coordination plane (A–PtN$_4$ = 90° and B–PtN$_4$ = 74°) indicating that there is little or no interaction between O(6) and O(6a) nor between the oxygen and the bmik ligand. Bond lengths and angles do not differ significantly from values reported for free guanine[22] except the internal ring angles C(5a)–N(7a)–C(8a) and C(5)–N(7)–C(8) differ ~3 and ~2° from the angle of the free base.

The two purine rings are slightly nonplanar indicated by a dihedral angle of ~3° between the two rings of the base. The imidazole rings of the bmik ligand are almost planar. The dihedral angle between the rings is 27°, indicating a significant deviation from the expected planarity of the free ligand. The bond lengths

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Table 3. Positional Parameters of Non-Hydrogen Atoms and Thermal Parameters (Å^2) for $[Pt(bmik)(9\text{-}MeGH)_2](ClO_4)_2\cdot 2H_2O$ (**1**)

atom	x	y	z	U_{eq}
Pt	0.1654(1)	0.1293(1)	0.3601(1)	0.017(1)
N(1)	0.2891(7)	0.0018(2)	0.1291(4)	0.026(1)
N(2)	0.4808(8)	–0.0446(2)	0.0708(5)	0.031(2)
N(3)	0.5658(7)	0.0100(2)	0.1852(4)	0.023(1)
N(7)	0.3507(7)	0.0934(2)	0.3146(4)	0.020(1)
N(9)	0.6042(6)	0.0716(2)	0.3029(4)	0.019(1)
N(1a)	0.4021(7)	0.2606(2)	0.1952(4)	0.022(1)
N(2a)	0.4137(8)	0.3031(2)	0.0492(4)	0.028(2)
N(3a)	0.2497(7)	0.2417(2)	0.0431(4)	0.023(1)
N(7a)	0.1507(7)	0.1603(2)	0.2256(4)	0.019(1)
N(9a)	0.0884(7)	0.1758(2)	0.0640(4)	0.023(1)
N(13)	0.1840(6)	0.0976(2)	0.4931(4)	0.019(1)
N(11)	0.2023(8)	0.0873(2)	0.6569(4)	0.031(2)
N(13a)	–0.0069(7)	0.1679(2)	0.4133(4)	0.018(1)
N(11a)	–0.1334(7)	0.2096(2)	0.5203(4)	0.022(1)
O(6)	0.0856(6)	0.0455(2)	0.1816(4)	0.038(1)
O(6a)	0.4139(6)	0.2189(2)	0.3398(3)	0.025(1)
O(16)	0.0784(6)	0.1761(2)	0.6822(4)	0.033(1)
C(2)	0.4469(9)	–0.0104(2)	0.1308(5)	0.024(2)
C(4)	0.5106(8)	0.0440(2)	0.2409(5)	0.019(1)
C(5)	0.3530(8)	0.0572(2)	0.2485(5)	0.022(2)
C(6)	0.2300(8)	0.0363(2)	0.1877(5)	0.025(2)
C(8)	0.5018(8)	0.1011(2)	0.3445(5)	0.024(2)
C(9)	0.7784(9)	0.0715(3)	0.3165(6)	0.034(2)
C(2a)	0.3537(9)	0.2674(2)	0.0947(5)	0.023(2)
C(4a)	0.1960(8)	0.2082(2)	0.0988(5)	0.021(2)
C(5a)	0.2331(9)	0.1983(2)	0.1993(5)	0.020(2)
C(6a)	0.3530(8)	0.2246(2)	0.2537(5)	0.022(2)
C(8a)	0.0675(9)	0.1474(2)	0.1416(5)	0.025(2)
C(9a)	0.0260(10)	0.1713(3)	–0.0410(5)	0.036(2)
C(11)	0.1847(11)	0.0928(3)	0.7672(6)	0.043(2)
C(12)	0.1564(8)	0.1161(2)	0.5828(5)	0.022(2)
C(14)	0.2481(9)	0.0560(2)	0.5123(6)	0.029(2)
C(15)	0.2587(10)	0.0498(3)	0.6134(6)	0.035(2)
C(16)	0.0775(8)	0.1590(2)	0.5984(5)	0.024(2)
C(11a)	–0.1831(9)	0.2303(3)	0.6146(6)	0.032(2)
C(12a)	–0.0152(8)	0.1788(2)	0.5114(5)	0.020(2)
C(14a)	–0.1243(9)	0.1918(2)	0.3604(6)	0.024(2)
C(15a)	–0.2033(9)	0.2170(2)	0.4269(5)	0.027(2)
Cl(1)	0.5923(2)	0.1456(1)	0.0715(1)	0.026(1)
O(11)	0.6216(8)	0.1626(2)	0.1718(4)	0.051(2)
O(12)	0.6094(9)	0.1817(2)	0.0016(4)	0.054(2)
O(13)	0.7088(7)	0.1110(2)	0.0538(5)	0.045(2)
O(14)	0.4355(7)	0.1268(2)	0.0580(5)	0.048(2)
Cl(2)	–0.3013(3)	0.0816(1)	0.6216(2)	0.041(1)
O(21†)^a	–0.3174(17)	0.1218(3)	0.5657(8)	0.058(3)
O(22†)	–0.3628(12)	0.0447(3)	0.5546(10)	0.061(3)
O(23†)	–0.3952(15)	0.0818(4)	0.7060(8)	0.074(3)
O(24†)	–0.1444(17)	0.0717(6)	0.6490(15)	0.113(6)
O(21a‡)	–0.2307(29)	0.0991(9)	0.7251(17)	0.080(8)
O(22a‡)	–0.3606(29)	0.0408(8)	0.6393(18)	0.068(7)
O(23a‡)	–0.4309(36)	0.1128(7)	0.5964(29)	0.114(15)
O(24a‡)	–0.1716(34)	0.0837(14)	0.5635(27)	0.121(13)
Ow(1)	–0.4069(9)	0.1715(2)	–0.2106(4)	0.059(2)
Ow(2)	0.8421(6)	0.0078(2)	0.0654(4)	0.041(1)

[a] sof's: (†) 0.65; (‡) 0.35.

and angles between the platinum and its donor atoms are typical of those found in other 9-methylguanine complexes.[1,21]

A complicated network of hydrogen bonds is observed between the water molecules, the perchlorate anions, and the exocyclic O(6), O(6a) and N(2), N(2a) atoms of the 9-methylguanine bases. A summary of the possible hydrogen-bonding distances and their estimated standard deviations is given in Table 5. The guanine bases in the molecular cation of **1** are head-to-tail oriented in contrast to four complexes of the type *cis*-$[(NH_3)_2Pt(9\text{-}EtGH)_2]X_2$ containing head-to-head oriented 9-ethylguanine ligands and different counterions.[23] Formation of a single hydrogen bond between the exocyclic oxygen atom of each guanine and a *cis*-ammine causes the head-to-head arrangement of the 9-ethylguanine ligands. If there is no possibility to form hydrogen bonds as in **1**, the two purines adopt the geometrically more favorable head-to-tail arrangement.

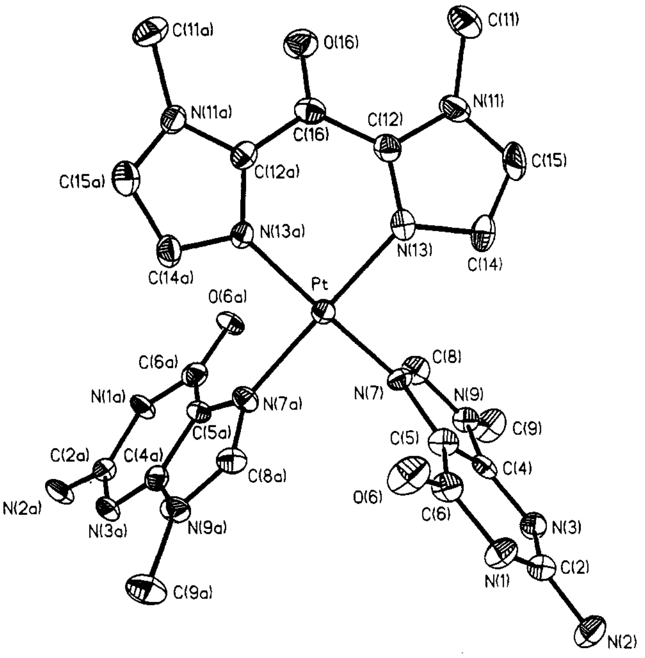

Figure 2. Molecular structure and labeling of $[Pt(bmik)(9\text{-}MeGH)_2]^{2+}$ in **1**.

Table 4. Selected Bond Lengths (Å) and Angles (deg) for $[Pt(bmik)(9\text{-}MeGH)_2](ClO_4)_2\cdot 2H_2O$ (**1**)

Pt–N(13)	1.995(5)	Pt–N(7a)	2.002(5)
Pt–N(13a)	2.004(5)	Pt–N(7)	2.005(6)
N(1)–C(2)	1.365(9)	N(1)–C(6)	1.397(9)
N(2)–C(2)	1.335(9)	N(3)–C(2)	1.334(9)
N(3)–C(4)	1.352(9)	N(7)–C(8)	1.317(8)
N(7)–C(5)	1.389(8)	N(9)–C(8)	1.367(9)
N(9)–C(4)	1.370(8)	N(9)–C(9)	1.453(9)
N(13)–C(12)	1.342(8)	N(13)–C(14)	1.367(8)
N(11)–C(12)	1.340(8)	N(11)–C(15)	1.357(10)
N(11)–C(11)	1.484(9)	N(13a)–C(12a)	1.343(8)
N(13a)–C(14a)	1.367(8)	N(11a)–C(15a)	1.350(9)
N(11a)–C(12a)	1.359(8)	N(11a)–C(11a)	1.475(9)
O(6)–C(6)	1.233(8)	O(16)–C(16)	1.220(8)
C(4)–C(5)	1.383(9)	C(5)–C(6)	1.408(9)
C(12)–C(16)	1.459(10)	C(14)–C(15)	1.348(10)
C(16)–C(12a)	1.468(9)	C(14a)–C(15a)	1.359(10)

N(13)–Pt–N(7a)	178.7(2)	N(13)–Pt–N(13a)	88.8(2)
N(7a)–Pt–N(13a)	92.5(2)	N(13)–Pt–N(7)	89.7(2)
N(7a)–Pt–N(7)	89.0(2)	N(13a)–Pt–N(7)	175.3(2)
C(2)–N(1)–C(6)	124.1(6)	C(2)–N(3)–C(4)	111.6(6)
C(8)–N(7)–C(5)	105.9(6)	C(8)–N(7)–Pt	123.9(5)
C(5)–N(7)–Pt	130.2(5)	C(8)–N(9)–C(4)	106.3(5)
C(8)–N(9)–C(9)	126.8(6)	C(4)–N(9)–C(9)	126.8(6)
C(12)–N(13)–C(14)	107.2(6)	C(12)–N(13)–Pt	25.3(4)
C(14)–N(13)–Pt	27.0(5)	C(12)–N(11)–C(15)	107.9(6)
C(12)–N(11)–C(11)	127.4(6)	C(15)–N(11)–C(11)	124.6(6)
C(12a)–N(13a)–C(14a)	106.8(6)	C(12a)–N(13a)–Pt	124.1(4)
C(14a)–N(13a)–Pt	128.8(5)	C(15a)–N(11a)–C(12a)	107.6(6)
C(15a)–N(11a)–C(11a)	125.3(6)	C(12a)–N(11a)–C(11a)	127.0(6)
N(3)–C(2)–N(2)	119.3(7)	N(3)–C(2)–N(1)	124.9(6)
N(2)–C(2)–N(1)	115.8(6)	N(3)–C(4)–N(9)	125.2(6)
N(3)–C(4)–C(5)	127.7(6)	N(9)–C(4)–C(5)	107.1(6)
C(4)–C(5)–N(7)	108.5(6)	C(4)–C(5)–C(6)	119.6(6)
N(7)–C(5)–C(6)	131.7(6)	O(6)–C(6)–N(1)	120.4(6)
O(6)–C(6)–C(5)	127.7(7)	N(1)–C(6)–C(5)	111.9(6)
N(7)–C(8)–N(9)	112.2(6)	N(11)–C(12)–N(13)	109.1(6)
N(11)–C(12)–C(16)	124.6(6)	N(13)–C(12)–C(16)	126.1(6)
C(15)–C(14)–N(13)	108.0(7)	C(14)–C(15)–N(11)	107.8(6)
O(16)–C(16)–C(12)	121.1(6)	O(16)–C(16)–C(12a)	121.2(7)
C(12)–C(16)–C(12a)	117.4(6)	N(13a)–C(12a)–N(11a)	109.3(6)
N(13a)–C(12a)–C(16)	127.1(6)	N(11a)–C(12a)–C(16)	123.5(6)
C(15a)–C(14a)–N(13a)	108.5(6)	N(11a)–C(15a)–C(14a)	107.7(6)

$[Pt(bmik)(1\text{-}MeC)_2](ClO_4)_2\cdot 1.5H_2O$. The N(3) site is the

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Table 5. Possible Hydrogen Bonds (Å) for $[Pt(bmik)(9\text{-}MeGH)_2](ClO_4)_2\cdot 2H_2O$ (**1**)[a]

Ow(1)–N($1a^{i}$)	2.817(8)	Ow(1)–O(12^{ii})	2.819(8)
Ow(1)–O($21a^{iii}$)	2.77(3)	Ow(1)–O(23^{iii})	2.896(13)
Ow(2)–N(3)	2.881(8)	Ow(2)–O(6^{iv})	2.712(7)
N(2)–O(13^{v})	2.968(8)	N(2)–O(14^{v})	3.089(8)
(N(2a)–O($6a^{vi}$)	2.848(7)	N(2a)–O($23a^{vii}$)	2.87(2)

X-H		H···Y		angle X-H···Y	
N(2)–H(2,2)	0.86*	H(2,2)···O(13^{v})	2.16	N(2)–H(2,2)···O(13^{v})	157
N(2a)–H(2a,1)	0.86*	H(2a,1)···O($6a^{vi}$)	2.15	N(2a)–H(2a,1)···O($6a^{vi}$)	138
H(2a)–H(2a,2)	0.86*	H(2a,2)···O($23a^{vii}$)	2.13	N(2a)–H(2a,2)···O($23a^{vii}$)	144

[a] Key to the symmetry operations: (i) $x - 1, y + 1/2, z - 1/2$; (ii) $x - 1, y, z$; (iii) $x, y, z - 1$; (iv) $x + 1, y, z$; (v) $-x + 1, -y, -z$; (vi) $x, -y + 1/2, z - 1/2$; (vii) $x + 1, -y + 1/2, z - 1/2$. An asterisk indicates a constrained value.

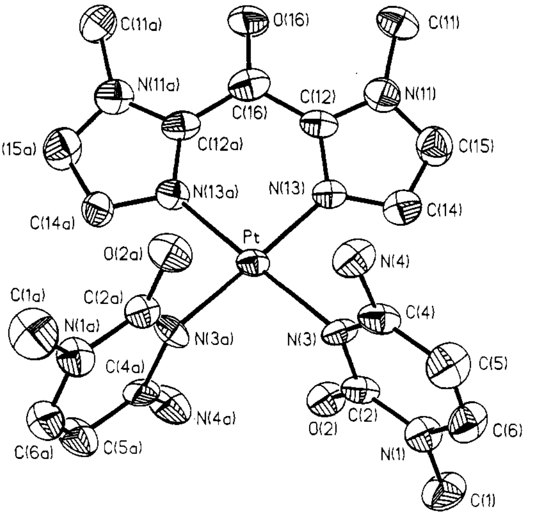

Figure 3. Geometry of the cation $[Pt(bmik)(1\text{-}MeC)_2]^{2+}$ in **2**.

preferred binding site of the soft Pt electrophile, as established by a large number of Pt nucleobase complexes characterized by X-ray crystallography.[24–40] The adjacent O(2) oxygen is, by contrast to complexes of other transition metals, in no instance involved in Pt binding. The possible involvement of cytosine in a *cis*-DDP cross-link with guanine and adenine in DNA has been discussed.[41–43]

The molecular cation is shown in Figure 3, the experimental details of the X-ray diffraction study are summarized in Table 1, the final atomic positional parameters together with their estimated standard deviations are reported in Table 6, and selected interatomic distances and angles are given in Table 7. In the molecular cation of **2** the platinum atom is coordinated by two 1-methylcytosine bases and a bmik ligand. The platinum has square-planar coordination, and Pt–N distances are normal. The two 1-methylcytosine ligands coordinate via their N(3) site with both bases arranged head-to-tail such that O(2) and O(2a) can

Table 6. Positional Parameters of Non-Hydrogen Atoms and Thermal Parameters (Å²) for $[Pt(bmik)(1\text{-}MeC)_2](ClO_4)_2\cdot 1.5H_2O$ (**2**)

atom	x	y	z	U_{eq}
Pt	0.1130(1)	0.4111(1)	0.3127(1)	0.028(1)
N(1)	0.1020(1)	0.5693(9)	0.1370(7)	0.038(2)
N(3)	0.1152(1)	0.4818(9)	0.2207(6)	0.032(2)
N(4)	0.1452(1)	0.4678(10)	0.2193(7)	0.043(3)
N(1a)	0.1146(1)	0.0759(9)	0.1503(7)	0.037(2)
N(3a)	0.1057(1)	0.2495(8)	0.2262(6)	0.034(2)
N(4a)	0.0752(1)	0.2594(10)	0.2186(8)	0.051(3)
N(11)	0.1355(1)	0.7099(10)	0.5136(7)	0.043(3)
N(13)	0.1216(1)	0.5705(9)	0.3991(6)	0.034(2)
N(11a)	0.1176(2)	0.3142(10)	0.5219(7)	0.046(3)
N(13a)	0.1115(1)	0.3431(9)	0.4046(6)	0.033(2)
O(2)	0.0851(1)	0.4932(8)	0.2197(6)	0.042(2)
O(2a)	0.1353(1)	0.2330(8)	0.2313(6)	0.041(2)
O(16)	0.1376(2)	0.5453(9)	0.5926(6)	0.063(3)
C(1)	0.0853(2)	0.6056(15)	0.1096(10)	0.059(4)
C(2)	0.1000(2)	0.5119(11)	0.1927(7)	0.035(3)
C(4)	0.1313(2)	0.5023(12)	0.1914(7)	0.037(3)
C(5)	0.1326(2)	0.5619(13)	0.1356(9)	0.050(4)
C(6)	0.1181(2)	0.5939(13)	0.1100(9)	0.045(3)
C(1a)	0.1294(2)	0.0078(14)	0.1274(11)	0.057(4)
C(2a)	0.1195(2)	0.1896(10)	0.2034(7)	0.031(3)
C(4a)	0.0877(2)	0.1997(11)	0.1944(8)	0.038(3)
C(5a)	0.0836(2)	0.0835(12)	0.1395(9)	0.048(4)
C(6a)	0.0972(2)	0.0257(12)	0.1187(9)	0.049(4)
C(11)	0.1446(2)	0.7784(13)	0.5984(9)	0.057(4)
C(12)	0.1290(2)	0.5949(11)	0.4779(7)	0.034(3)
C(14)	0.1238(2)	0.6721(12)	0.3850(9)	0.044(3)
C(15)	0.1323(2)	0.5795(13)	0.4561(9)	0.051(4)
C(16)	0.1294(2)	0.5131(12)	0.5232(8)	0.043(3)
C(11a)	0.1243(2)	0.3319(14)	0.6098(9)	0.056(4)
C(12a)	0.1197(2)	0.3927(11)	0.4821(7)	0.036(3)
C(14a)	0.1041(2)	0.2315(11)	0.3952(8)	0.042(3)
C(15a)	0.1077(2)	0.2138(14)	0.4677(9)	0.054(4)
Cl(1)	0.0435(1)	0.2386(3)	0.0013(2)	0.049(1)
O(11)	0.0415(3)	0.1866(17)	−0.0858(9)	0.138(7)
O(12)	0.0263(2)	0.2229(14)	0.0322(10)	0.095(4)
O(13)	0.0507(2)	0.3557(12)	0.0210(10)	0.109(6)
O(14)	0.0551(2)	0.1904(17)	0.0387(11)	0.119(6)
Cl(2)	0.0903(1)	0.0873(5)	0.6857(4)	0.091(2)
O(21)	0.1038(5)	0.0538(31)	0.7252(18)	0.239(15)
O(22)	0.0764(5)	0.0046(26)	0.6833(19)	0.266(20)
O(23)	0.0936(4)	0.0803(19)	0.6050(12)	0.161(9)
O(24)	0.0905(5)	0.1942(15)	0.7301(14)	0.240(18)
Ow(1)	0.0924(3)	0.2966(18)	0.0305(13)	0.139(7)
Ow(2)	0.0342(4)	0.0369(24)	0.5632(27)	0.128(14)

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Table 7. Selected Bond Lengths (Å) and Angles (deg) for $[Pt(bmik)(1\text{-}MeC)_2](ClO_4)_2 \cdot 1.5H_2O$ (**2**)

Pt–N(13)	2.024(10)	Pt–N(13a)	2.025(10)
Pt–N(3a)	2.035(10)	Pt–N(3)	2.049(9)
N(1)–C(6)	1.37(2)	N(1)–C(2)	1.37(2)
N(1)–C(1)	1.48(2)	N(3)–C(4)	1.35(2)
N(3)–C(2)	1.37(2)	N(4)–C(4)	1.32(2)
N(11)–C(12)	1.35(2)	N(11)–C(15)	1.36(2)
N(11)–C(11)	1.48(2)	N(13)–C(12)	1.35(2)
N(13)–C(14)	1.35(2)	N(11a)–C(15a)	1.35(2)
N(11a)–C(12a)	1.36(2)	N(11a)–C(11a)	1.50(2)
N(13a)–C(12a)	1.33(2)	N(13a)–C(14a)	1.36(2)
O(2)–C(2)	1.25(1)	O(16)–C(16)	1.22(2)
C(4)–C(5)	1.39(2)	C(5)–C(6)	1.32(2)
C(4a)–C(5a)	1.48(2)	C(5a)–C(6a)	1.34(2)
C(12)–C(16)	1.48(2)	C(14)–C(15)	1.37(2)
C(16)–C(12a)	1.47(2)	C(14a)–C(15a)	1.35(2)
N(13)–Pt–N(13a)	89.4(4)	N(13)–Pt–N(3a)	177.0(4)
N(13a)–Pt–N(3a)	90.2(4)	N(13)–Pt–N(3)	89.8(4)
N(13a)–Pt–N(3)	178.5(4)	N(3a)–Pt–N(3)	90.5(4)
C(6)–N(1)–C(2)	119.9(11)	C(6)–N(1)–C(1)	122.0(12)
C(2)–N(1)–C(1)	118.1(11)	C(4)–N(3)–C(2)	121.3(10)
C(4)–N(3)–Pt	120.9(8)	C(2)–N(3)–Pt	117.7(8)
C(12)–N(11)–C(15)	107.5(11)	C(12)–N(11)–C(11)	130.3(12)
C(15)–N(11)–C(11)	122.2(12)	C(12)–N(13)–C(14)	106.6(11)
C(12)–N(13)–Pt	126.5(9)	C(14)–N(13)–Pt	126.1(9)
C(15a)–N(11a)–C(12a)	107.5(11)	C(15a)–N(11a)–C(11a)	124.4(12)
C(12a)–N(11a)–C(11a)	128.1(12)	C(12a)–N(13a)–C(14a)	106.9(11)
C(12a)–N(13a)–Pt	126.7(9)	C(14a)–N(13a)–Pt	125.7(8)
O(2)–C(2)–N(3)	121.4(11)	O(2)–C(2)–N(1)	119.9(11)
N(3)–C(2)–N(1)	118.5(10)	N(4)–C(4)–N(3)	118.1(11)
N(4)–C(4)–C(5)	122.9(11)	N(3)–C(4)–C(5)	119.0(11)
C(6)–C(5)–C(4)	119.8(12)	C(5)–C(6)–N(1)	121.4(13)
N(13)–C(12)–N(11)	109.9(11)	N(13)–C(12)–C(16)	127.2(11)
N(11)–C(12)–C(16)	122.8(11)	N(13)–C(14)–C(15)	108.9(13)
N(11)–C(15)–C(14)	107.1(13)	O(16)–C(16)–C(12a)	121.5(13)
O(16)–C(16)–C(12)	120.5(13)	C(12a)–C(16)–C(12)	118.0(11)
N(13a)–C(12a)–N(11a)	109.4(11)	N(13a)–C(12a)–C(16)	128.1(12)
N(11a)–C(12a)–C(16)	122.4(11)	C(15a)–C(14a)–N(13a)	109.0(12)
N(11a)–C(15a)–C(14a)	107.2(13)		

hydrogen-bond intramolecularly to N(4a) and N(4) as observed in the *cis*-DDP analog structure.[27] The distances are O(2a)–N(4) = 2.98 Å and O(2)–N(4a) = 2.88 Å. The two metal-bonded rings are almost planar at a dihedral angle of 80° to each other and 93° (94°) to the platinum square plane (102, 79, and 78° in ref 27). The distances Pt···O(2) and Pt···O(2a) are 3.07 and 3.03 Å, being long enough to exclude any significant bonding interactions.

The changes in the observed internal angles going from unbonded to bonded cytosine at C(5) (+2°) and C(5a) (+1°) are in the direction noted in ref 43; all other angles show no significant deviations. The imidazole rings of the bmik ligand are essentially planar with a dihedral angle of 9° between them, so the deviation from the expected planarity of the free ligand is less distinct in comparison to **1**.

The hydrogen bonds between the exocyclic groups of the 1-methylcytosine ligands are most important, forcing the two rings into a head-to-tail orientation. Additionally we found hydrogen bonding between the water molecules and the perchlorate anions. A summary of all possible hydrogen-bond distances is given in Table 8.

In $[Pt(NH_3)_2(Me\text{-}C)_2]^{2+}$ (head-to-tail isomer) the dihedral angle between the two 1-methylcytosine rings is larger than in **2**. The two bases within the $[Pt(NH_3)_2(Me\text{-}C)_2]^{2+}$ dication are rotated around their N(3)–Pt vector having dihedral angles with the platinum coordination plane of approximately 78° while these angles are nearly rectangular in **2**. One reason for this difference might be the lack of structure-determining hydrogen bonds between the exocyclic oxygen atoms and the bmik ligand, in contrast to significant bonding in $[Pt(NH_3)_2(Me\text{-}C)_2]^{2+}$.

$[Pt_2(bmik)_2(1\text{-}MeT)_2](ClO_4)_2 \cdot 5H_2O$. The favorite locations for platinum to coordinate to the DNA at physiological pH are the unprotonated N(7) sites of the purine bases. With unwound DNA, as with single-stranded RNA (uracil replacing thymine) and single-stranded oligonucleotides, Pt binding to the thymine and uracil in principle is possible. Both simple complexes of 1-MeUH and platinum pyrimidine blues[44–47] have been found to exhibit antitumor activity. Additionally, dinuclear complexes of the type *cis*-$[a_2PtCl_2]$ containing two deprotonated cyclic amide ligands such as α-pyridone, α-pyrrolidone, 1-methyluracil, and 1-methylthymine have aroused substantial interest because of their assumed role as precursors of "platinum pyrimidine blues". In our group we synthesized an oxidized ($Pt^{2.25+}$) α-pyridonate-bridged complex with head-to-tail orientation of the bases containing 1,1′-dimethyl-2,2′-bis(imidazole) as ligand forming a one-dimensional helical Pt chain.[3c]

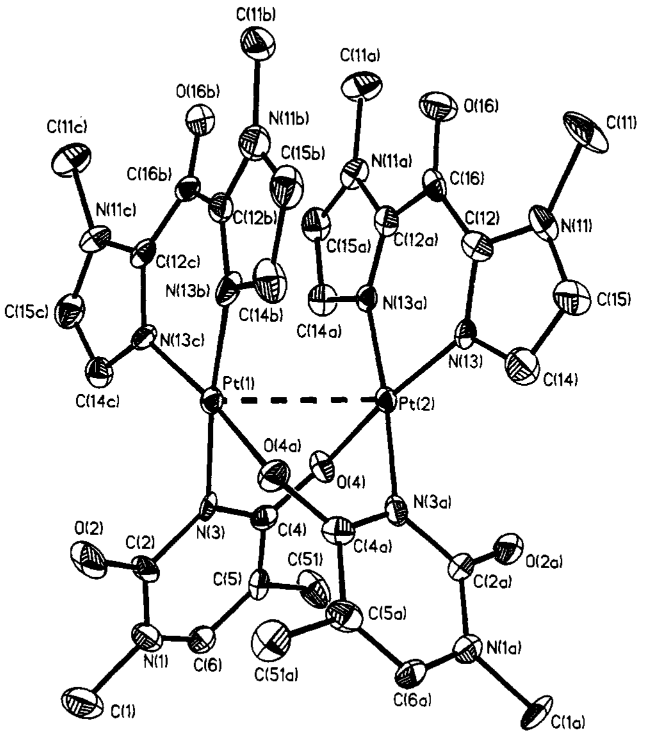

Figure 4. Dinuclear cation and labeling of $[Pt_2(bmik)_2(1\text{-}MeT)_2]^{2+}$ in **3**.

In Figure 4 a view of the dinuclear cation of **3** is given. Table 1 lists the experimental details of the X-ray diffraction study, Table 9 gives final atomic positional parameters together with their estimated standard deviations, and Table 10 gives selected distances and angles with estimated standard deviations for **3**. Distances and angles are given for one bmik and one 1-MeT base because they are representative for those of the other ligands within one estimated standard deviation. The cation consists of two (bmik)Pt^{II} units each bridged by two 1-methylthyminato ligands through N(3) and O(4). The 1-MeT ligands are arranged in head-to-tail fashion. The intramolecular Pt···Pt distance is 2.900 Å, and both Pt atoms are slightly out (0.08 Å) of their coordination planes, directed toward each other. The N(3)···O(4) and N(3a)···O(4a) bite distances (2.29, 2.30 Å) are considerably shorter than the Pt···Pt distance, and this, together with the square planar arrangement about each platinum atom, causes the two platinum coordination planes to splay apart (dihedral angle 11°). In addition, the planes are rotated by 23° so that the atoms coordinated to one platinum atom do not lie directly above those of the other when viewed down the Pt···Pt vector (see Figure 5).

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Table 8. Possible Hydrogen Bonds (Å) for [Pt(bmik)(1-MeC)$_2$](ClO$_4$)$_2$·1.5H$_2$O (**2**)^a

Ow(1)–O(14)	2.93(3)	Ow(1)–O(12^{ii})	2.85(2)
O(2)–N(4^{i})	2.96(1)	O(2a)–N(4a^{ii})	2.98(1)
O(2a)–N(4)	2.98(2)	O(2)–N(4a)	2.88(2)

X-H		H···Y		angle X-H···Y	
N(4a)–H(4a,1)	0.86*	H(4a,1)···O(2)	2.30	N(4a)–H(4a,1)···O(2)	125
N(4)–H(4,1)	0.86*	H(4,1)···O(2a)	2.36	N(4)–H(4,1)···O(2a)	129
N(4)–H(4,2)	0.86*	H(4,2)···O(2^{i})	2.19	N(4)–H(4,2)···O(2^{i})	120
N(4a)–H(4a,2)	0.86*	H(4a,2)···O(2a^{ii})	2.25	N(4a)–H(4a,2)···O(2a^{ii})	116

^{a} Key to the symmetry operations: (i) $x - 1, y, z$; (ii) $x + 1, y, z$. An asterisk indicates a constrained value.

Table 9. Positional Parameters of Non-Hydrogen Atoms and Thermal Parameters (Å) for [Pt$_2$(bmik)$_2$(1-MeT)$_2$](ClO$_4$)$_2$·5H$_2$O (**3**)

atom	x	y	z	U_{eq}
Pt(1)	0.0890(1)	0.4043(1)	0.1469(1)	0.016(1)
Pt(2)	0.0181(1)	0.3218(1)	0.3425(1)	0.015(1)
N(1)	0.3122(8)	0.5691(8)	0.1668(6)	0.030(2)
N(3)	0.1625(7)	0.4845(6)	0.1962(5)	0.016(2)
N(1a)	0.3794(8)	0.1774(8)	0.3642(6)	0.028(2)
N(3a)	0.2050(8)	0.2534(7)	0.3112(6)	0.021(2)
N(11)	−0.0925(8)	0.0595(7)	0.3697(6)	0.025(2)
N(13)	−0.0066(8)	0.1819(7)	0.3547(6)	0.021(2)
N(11a)	−0.3573(7)	0.4385(7)	0.3697(6)	0.021(2)
N(13a)	−0.1647(7)	0.3985(7)	0.3650(5)	0.016(2)
N(11b)	−0.1338(10)	0.2619(8)	0.1054(7)	0.031(2)
N(13b)	0.0120(9)	0.3178(7)	0.1113(6)	0.025(2)
N(11c)	−0.2229(8)	0.6464(7)	0.1173(6)	0.024(2)
N(13c)	−0.0442(8)	0.5362(7)	0.1287(6)	0.022(2)
O(2)	0.2961(7)	0.5049(8)	0.0481(5)	0.035(2)
O(4)	0.0418(7)	0.4614(6)	0.3478(5)	0.022(2)
O(2a)	0.1842(7)	0.2303(7)	0.4680(5)	0.033(2)
O(4a)	0.2364(7)	0.2740(6)	0.1521(5)	0.025(2)
O(16)	−0.3059(7)	0.2222(7)	0.3374(6)	0.032(2)
O(16b)	−0.3094(7)	0.4675(7)	0.1563(5)	0.029(2)
C(1)	0.4121(11)	0.6071(13)	0.1024(9)	0.044(3)
C(2)	0.2613(9)	0.5176(9)	0.1312(7)	0.021(2)
C(4)	0.1248(9)	0.4991(8)	0.2875(7)	0.018(2)
C(5)	0.1736(9)	0.5584(8)	0.3207(7)	0.020(2)
C(51)	0.1224(12)	0.5813(10)	0.4229(8)	0.035(3)
C(6)	0.2644(10)	0.5928(9)	0.2591(7)	0.026(2)
C(1a)	0.4334(12)	0.1414(12)	0.4424(9)	0.046(4)
C(2a)	0.2507(9)	0.2224(9)	0.3871(7)	0.023(2)
C(4a)	0.2793(9)	0.2431(8)	0.2218(7)	0.019(2)
C(5a)	0.4085(9)	0.1979(9)	0.2012(8)	0.025(2)
C(51a)	0.4867(10)	0.1917(10)	0.1006(8)	0.031(3)
C(6a)	0.4542(9)	0.1669(9)	0.2736(8)	0.029(2)
C(11)	−0.1845(12)	0.0065(10)	0.3863(11)	0.042(3)
C(12)	−0.1112(9)	0.1663(8)	0.3575(7)	0.020(2)
C(14)	0.0756(10)	0.0836(9)	0.3621(9)	0.032(3)
C(15)	0.0228(10)	0.0087(8)	0.3721(9)	0.029(2)
C(16)	−0.2276(9)	0.2461(8)	0.3518(7)	0.021(2)
C(11a)	−0.4744(9)	0.4317(10)	0.3721(9)	0.034(3)
C(12a)	−0.2466(8)	0.3579(8)	0.3627(7)	0.019(2)
C(14a)	−0.2189(9)	0.5051(8)	0.3718(7)	0.022(2)
C(15a)	−0.3380(10)	0.5291(9)	0.3747(8)	0.027(2)
C(11b)	−0.2500(11)	0.2578(11)	0.1028(8)	0.036(3)
C(12b)	−0.1075(10)	0.3486(8)	0.1164(7)	0.022(2)
C(14b)	0.0622(12)	0.2118(9)	0.0988(8)	0.030(2)
C(15b)	−0.0284(12)	0.1774(9)	0.0944(8)	0.032(3)
C(16b)	−0.1986(9)	0.4533(9)	0.1335(6)	0.019(2)
C(11c)	−0.3445(10)	0.6905(10)	0.1021(9)	0.035(3)
C(12c)	−0.1552(9)	0.5417(8)	0.1259(6)	0.019(2)
C(14c)	−0.0434(10)	0.6380(8)	0.1252(7)	0.023(2)
C(15c)	−0.1562(11)	0.7078(9)	0.1184(8)	0.029(2)
Cl(1)	0.3628(3)	0.7982(3)	0.3832(2)	0.037(1)
O(11)	0.2382(12)	0.8161(15)	0.4371(8)	0.113(6)
O(12)	0.4358(14)	0.7625(15)	0.4441(11)	0.113(6)
O(13)	0.3976(20)	0.7456(22)	0.3073(12)	0.179(12)
O(14)	0.3667(18)	0.9065(14)	0.3509(18)	0.157(9)
Cl(2)	0.0794(4)	0.8589(3)	0.1548(3)	0.055(1)
O(21)	0.0155(22)	0.8182(20)	0.2395(13)	0.167(10)
O(22)	0.1454(17)	0.7679(14)	0.1081(12)	0.117(6)
O(23)	0.0065(27)	0.9225(18)	0.1022(20)	0.197(12)
O(24)	0.1307(37)	0.9215(28)	0.1659(19)	0.270(19)
Ow(1)	0.8231(11)	0.7387(7)	0.3560(6)	0.051(3)
Ow(2)	0.6336(12)	0.9103(9)	0.3126(9)	0.071(3)
Ow(3)	0.7574(13)	−0.0051(11)	0.1417(11)	0.092(5)
Ow(4)	0.6580(14)	0.9429(10)	0.0262(12)	0.101(5)
Ow(5)	0.4067(18)	0.9581(17)	0.1311(12)	0.127(7)

Table 10. Selected Bond Lengths (Å) and Angles (deg) for [Pt$_2$(bmik)$_2$(1-MeT)$_2$](ClO$_4$)$_2$·5H$_2$O (**3**)

Pt(1)–N(13c)	1.963(8)	Pt(1)–N(13b)	1.988(8)
Pt(1)–O(4a)	2.009(7)	Pt(1)–N(3)	2.015(8)
Pt(1)–Pt(2)	2.900(1)	Pt(2)–N(13)	1.959(8)
Pt(2)–O(4)	2.007(7)	Pt(2)–N(13a)	2.024(8)
Pt(2)–N(3a)	2.040(8)	N(1)–C(2)	1.369(13)
N(1)–C(6)	1.377(14)	N(1)–C(1)	1.451(14)
N(3)–C(4)	1.338(12)	N(3)–C(2)	1.411(12)
N(11)–C(15)	1.336(14)	N(11)–C(12)	1.339(13)
N(11)–C(11)	1.463(13)	N(13)–C(14)	1.341(13)
N(13)–C(12)	1.357(12)	N(11a)–C(15a)	1.335(14)
N(11a)–C(12a)	1.371(12)	N(11a)–C(11a)	1.458(13)
N(13a)–C(12a)	1.317(12)	N(13a)–C(14a)	1.338(12)
O(2)–C(2)	1.215(12)	O(4)–C(4)	1.284(12)
O(16)–C(16)	1.216(12)	C(4)–C(5)	1.405(13)
C(5)–C(6)	1.333(14)	C(5)–C(51)	1.513(14)
C(12)–C(16)	1.454(14)	C(14)–C(15)	1.33(2)
C(16)–C(12a)	1.456(14)	C(14a)–C(15a)	1.360(14)
N(13c)–Pt(1)–N(13b)	89.5(3)	N(13c)–Pt(1)–O(4a)	173.9(3)
N(13b)–Pt(1)–O(4a)	91.6(3)	N(13c)–Pt(1)–N(3)	92.7(3)
N(13b)–Pt(1)–N(3)	174.2(3)	O(4a)–Pt(1)–N(3)	86.7(3)
N(13)–Pt(2)–O(4)	172.5(3)	N(13)–Pt(2)–N(13a)	90.4(3)
O(4)–Pt(2)–N(13a)	90.3(3)	N(13)–Pt(2)–N(3a)	92.7(3)
O(4)–Pt(2)–N(3a)	87.1(3)	N(13a)–Pt(2)–N(3a)	175.5(3)
C(2)–N(1)–C(6)	121.6(9)	C(2)–N(1)–C(1)	118.0(9)
C(6)–N(1)–C(1)	120.1(10)	C(4)–N(3)–C(2)	121.7(8)
C(4)–N(3)–Pt(1)	121.4(6)	C(2)–N(3)–Pt(1)	116.8(6)
C(15)–N(11)–C(12)	108.3(9)	C(15)–N(11)–C(11)	124.9(9)
C(12)–N(11)–C(11)	126.6(9)	C(14)–N(13)–C(12)	106.9(9)
C(14)–N(13)–Pt(2)	126.9(7)	C(12)–N(13)–Pt(2)	126.2(7)
C(15a)–N(11a)–C(12a)	105.6(8)	C(15a)–N(11a)–C(11a)	125.1(9)
C(12a)–N(11a)–C(11a)	129.2(9)	C(12a)–N(13a)–C(14a)	108.2(8)
C(12a)–N(13a)–Pt(2)	127.2(7)	C(14a)–N(13a)–Pt(2)	124.1(7)
O(2)–C(2)–N(1)	122.0(9)	O(2)–C(2)–N(3)	122.2(9)
N(1)–C(2)–N(3)	115.8(8)	O(4)–C(4)–N(3)	121.7(8)
O(4)–C(4)–C(5)	117.4(9)	N(3)–C(4)–C(5)	120.9(9)
C(6)–C(5)–C(4)	117.4(9)	C(6)–C(5)–C(51)	122.6(9)
C(4)–C(5)–C(51)	120.0(9)	C(5)–C(6)–N(1)	122.0(10)
N(11)–C(12)–N(13)	107.9(9)	N(11)–C(12)–C(16)	123.0(9)
N(13)–C(12)–C(16)	129.0(9)	C(15)–C(14)–N(13)	108.9(10)
C(14)–C(15)–N(11)	108.0(9)	O(16)–C(16)–C(12)	122.2(10)
O(16)–C(16)–C(12a)	120.7(10)	C(12)–C(16)–C(12a)	117.1(9)
N(13a)–C(12a)–N(11a)	109.7(9)	N(13a)–C(12a)–C(16)	127.5(9)
N(11a)–C(12a)–C(16)	122.8(9)	N(13a)–C(14a)–C(15a)	107.4(9)
N(11a)–C(15a)–C(14a)	109.1(9)		

The Pt···Pt distance in **3** is shorter than in the analogous [(NH$_3$)$_2$Pt(1-MeT)$_2$Pt(NH$_3$)$_2$]$^{2+}$ (head-to-tail) compound[48] (2.974 Å) so that the dihedral angle of the platinum coordination planes splaying apart is only 11° in contrast to 36° found in the *cis*-diammine analog complex.

The Pt–N and Pt–O distances do not differ significantly and are similar to values found for 1-MeT bridged compounds.[48] The imidazole rings of the bmik ligand are almost planar. A dihedral angle of 11° between the two rings is found while the O(16) and O(16b) oxygen atoms are directed toward each other. The 1-MeT bases are almost planar having a dihedral angle of 54°. The bite distances of the bases found in the structure of **3** (2.29, 2.30 Å) are slightly larger than for the free base[49] (2.27 Å) so that the internal angles N(3)–C(4)–O(4) and N(3a)–C(4a)–O(4a) are getting wider (average 3°) in comparison to free 1-MeTH. Due

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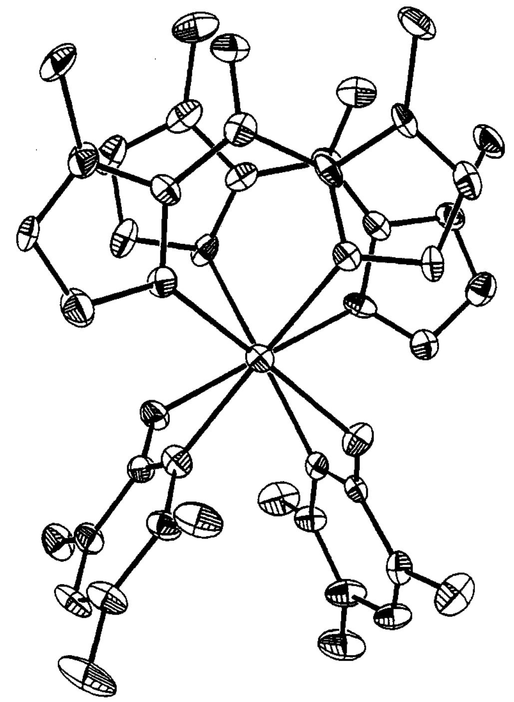

Figure 5. Molecular cation of $[Pt_2(bmik)_2(1\text{-}MeT)_2](ClO_4)_2 \cdot 5H_2O$ (3) viewed down the Pt–Pt axis.

Table 11. Possible Hydrogen Bonds (Å) for $[Pt_2(bmik)_2(1\text{-}MeT)_2](ClO_4)_2 \cdot 5H_2O$ (3)[a]

Ow(1)–O(2a^{i})	2.78(1)	Ow(1)–O(21^{ii})	2.81(2)
Ow(1)–Ow(2)	2.77(2)	Ow(2)–Ow(3^{iii})	2.82(2)
Ow(3)–O(23^{iv})	2.71(3)	Ow(3)–Ow(4^{v})	2.79(2)
Ow(4)–Ow(5)	2.87(2)	Ow(4)–Ow(5^{vi})	2.74(2)

[a] Key to the symmetry operations: (i) $-x + 1, -y + 1, -z + 1$; (ii) $x + 1, y, z$; (iii) $x, -y + 1, z$; (iv) $x + 1, y - 1, z$; (v) $x, y - 1, z$; (vi) $-x + 1, -y + 2, -z$.

to the deprotonation and coordination[43,50] of the nitrogen atom the angles C(2)–N(3)–C(4) and C(2a)–N(3a)–C(4a) are found to be smaller than in the free 1-methylthymine ligand.

The platinum atoms in adjacent cations are a long distance apart (5.46 Å). In the crystal structure of Lippert's head-to-head isomer[51] $[(NH_3)_2Pt(1\text{-}MeT)_2Pt(NH_3)_2]^{2+}$ hydrogen bonding occurs between the exocyclic O(2) sites of one cation with the two NH_3 groups of the adjacent cation forming infinite strands. In contrast, the present bis(imidazole) ligands are tertiary amines so that no hydrogen bonds can be formed. This allows a more flexible arrangement of the dinuclear cations with long intermolecular Pt···Pt distances.

A network of hydrogen bonds between the water molecules, the ketone group of the 1-MeT base, and the perchlorate anions is present in the crystal. A summary of possible hydrogen-bonding distances is given in Table 11.

$[Pt_2(bmik)_2(1\text{-}MeU)_2](NO_3)_2 \cdot 2H_2O$. A list of the experimental details of the X-ray diffraction study is given in Table 1. The final atomic positional parameters together with their estimated standard deviations are reported in Table 12, and selected interatomic distances and angles are given in Table 13. The molecular cation is shown in Figure 6. The cation is dinuclear, being bridged by 1-methyluracilato ligands through N(3) and O(4). The asymmetric unit contains only half of the cation, the other one being generated by a crystallographic 2-fold rotation axis. The atoms N(3) and O(4) and the two nitrogen atoms of the bmik ligand form a square plane about each platinum atom. The 1-MeU ligands are head-to-tail oriented; thus, the cation is in general like the 1-methylthyminato complex described above, however, with some of the differences being significant. The N–O bite distances of 2.29 and 2.30 Å in the 1-MeT complex are

Table 12. Positional Parameters of Non-Hydrogen Atoms and Thermal Parameters (Å^2) for $[Pt_2(bmik)_2(1\text{-}MeU)_2](NO_3)_2 \cdot 2H_2O$ (4)

atom	x	y	z	U_{eq}
Pt	0.0963(1)	0.0437(1)	0.2280(1)	0.013(1)
N(1)	0.0912(4)	0.3505(4)	0.1309(2)	0.019(1)
N(3)	0.0506(3)	0.1860(4)	0.1855(2)	0.015(1)
N(11)	0.1472(4)	−0.2771(4)	0.2957(2)	0.019(1)
N(13)	0.1332(3)	−0.0979(4)	0.2718(2)	0.017(1)
N(11a)	0.0883(4)	−0.1755(4)	0.0812(2)	0.019(1)
N(13a)	0.0927(3)	−0.0393(4)	0.1498(2)	0.015(1)
O(2)	0.2062(3)	0.2446(4)	0.1761(2)	0.026(1)
O(4)	−0.1094(3)	0.1345(3)	0.1937(2)	0.019(1)
O(16)	0.0784(3)	−0.3366(3)	0.1772(2)	0.021(1)
C(1)	0.1651(5)	0.4277(6)	0.1092(3)	0.029(2)
C(2)	0.1216(4)	0.2600(5)	0.1657(3)	0.020(1)
C(4)	−0.0445(4)	0.2008(5)	0.1725(3)	0.017(1)
C(5)	−0.0723(4)	0.2916(5)	0.1343(3)	0.021(1)
C(6)	−0.0040(4)	0.3627(5)	0.1146(3)	0.022(1)
C(11)	0.1521(5)	−0.4007(5)	0.2924(3)	0.021(1)
C(12)	0.1252(4)	−0.2043(5)	0.2505(3)	0.016(1)
C(14)	0.1571(4)	−0.1056(5)	0.3323(3)	0.018(1)
C(15)	0.1637(4)	−0.2169(5)	0.3468(3)	0.021(1)
C(16)	0.0968(4)	−0.2383(5)	0.1893(3)	0.017(1)
C(11a)	0.0961(5)	−0.2846(5)	0.0515(3)	0.028(1)
C(12a)	0.0935(4)	−0.1523(5)	0.1418(3)	0.017(1)
C(14a)	0.0866(4)	0.0075(5)	0.0930(3)	0.019(1)
C(15a)	0.0843(5)	−0.0759(5)	0.0508(3)	0.022(1)
N(21)	0.7041(4)	0.0353(4)	0.0460(2)	0.023(1)
O(21)	0.7716(3)	0.0993(4)	0.0600(2)	0.035(1)
O(22)	0.7191(4)	−0.0680(4)	0.0405(2)	0.035(1)
O(23)	0.6193(3)	0.0721(4)	0.0418(2)	0.035(1)
Ow(1)	0.6216(4)	0.2970(5)	−0.0069(3)	0.043(1)

Table 13. Selected Bond Lengths (Å) and Angles (deg) for $[Pt_2(bmik)_2(1\text{-}MeU)_2](NO_3)_2 \cdot 2H_2O$ (4)[a]

Pt–N(13a)	1.982(4)	Pt–N(13)	2.005(5)
Pt–N(3)	2.033(5)	Pt–O(4^{i})	2.038(4)
Pt–Pt^{i}	2.841(1)	N(1)–C(6)	1.375(8)
N(1)–C(2)	1.386(8)	N(1)–C(1)	1.456(7)
N(3)–C(4)	1.360(7)	N(3)–C(2)	1.391(7)
N(11)–C(12)	1.353(7)	N(11)–C(15)	1.360(8)
N(11)–C(11)	1.474(7)	N(13)–C(12)	1.353(7)
N(13)–C(14)	1.372(7)	N(11a)–C(15a)	1.360(8)
N(11a)–C(12a)	1.361(7)	N(11a)–C(11a)	1.455(7)
N(13a)–C(12a)	1.355(7)	N(13a)–C(14a)	1.368(7)
O(2)–C(2)	1.209(7)	O(4)–C(4)	1.284(7)
O(4)–Pt^{i}	2.038(4)	O(16)–C(16)	1.226(7)
C(4)–C(5)	1.421(8)	C(5)–C(6)	1.342(8)
C(12)–C(16)	1.457(8)	C(14)–C(15)	1.368(8)
C(16)–C(12a)	1.462(8)	C(14a)–C(15a)	1.358(9)
N(13a)–Pt–N(13)	90.2(2)	N(13a)–Pt–N(3)	90.5(2)
N(13)–Pt–N(3)	176.5(2)	N(13a)–Pt–O(4^{i})	175.7(2)
N(13)–Pt–O(4^{i})	91.0(2)	N(3)–Pt–O(4^{i})	88.5(2)
N(13a)–Pt–Pt^{i}	105.70(13)	N(13)–Pt–Pt^{i}	94.43(13)
N(3)–Pt–Pt^{i}	82.09(13)	O(4)–Pt–Pt^{i}	78.31(11)
C(6)–N(1)–C(2)	121.2(5)	C(6)–N(1)–C(1)	121.6(5)
C(2)–N(1)–C(1)	117.1(5)	C(4)–N(3)–C(2)	122.6(5)
C(4)–N(3)–Pt	120.4(4)	C(2)–N(3)–Pt	116.7(4)
C(12)–N(11)–C(15)	108.4(5)	C(12)–N(11)–C(11)	127.8(5)
C(15)–N(11)–C(11)	123.8(5)	C(12)–N(13)–C(14)	107.0(5)
C(12)–N(13)–Pt	126.8(4)	C(14)–N(13)–Pt	125.6(4)
C(15a)–N(11a)–C(12a)	107.8(5)	C(15a)–N(11a)–C(11a)	124.1(5)
C(12a)–N(11a)–C(11a)	127.8(5)	C(12a)–N(13a)–C(14a)	106.6(5)
C(12a)–N(13a)–Pt	127.4(4)	C(14a)–N(13a)–Pt	126.0(4)
C(4)–O(4)–Pt^{i}	124.6(4)	O(2)–C(2)–N(1)	121.1(6)
O(2)–C(2)–N(3)	122.2(6)	N(1)–C(2)–N(3)	116.6(5)
O(4)–C(4)–N(3)	121.6(5)	O(4)–C(4)–C(5)	119.3(5)
N(3)–C(4)–C(5)	119.1(5)	C(6)–C(5)–C(4)	118.5(5)
C(5)–C(6)–N(1)	121.9(5)	N(13)–C(12)–N(11)	109.0(5)
N(13)–C(12)–C(16)	126.9(5)	N(11)–C(2)–C(16)	124.1(5)
C(15)–C(14)–N(13)	108.4(5)	N(11)–C(15)–C(14)	107.1(5)
O(16)–C(16)–C(12)	121.5(5)	O(16)–C(16)–C(12a)	120.3(6)
C(12)–C(16)–C(12a)	118.2(5)	N(13a)–C(12a)–N(11a)	109.1(5)
N(13a)–C(12a)–C(16)	126.9(5)	N(11a)–C(12a)–C(16)	124.0(5)
C(15a)–C(14a)–N(13a)	109.0(6)	C(14a)–C(15a)–N(11a)	107.5(5)

[a] Key to the symmetry operation: (i) $-x, y, -z + 1/2$.

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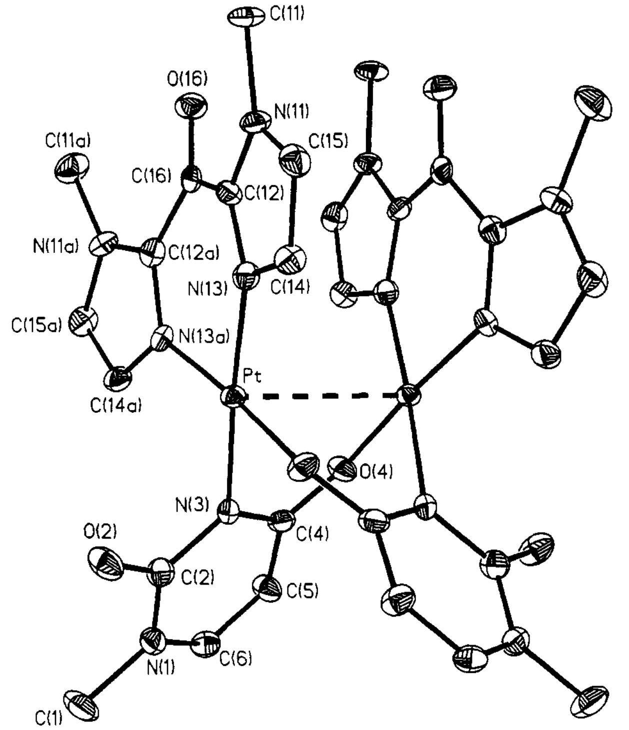

Figure 6. View of the dinuclear cation $[Pt_2(bmik)_2(1\text{-}MeU)_2]^{2+}$ in **4** with the 1-MeU ligands arranged in head-to-tail fashion.

comparable to the value of 2.31 Å in the 1-MeU complex. The Pt–Pt distance of 2.900 Å compares with 2.841 Å, the dihedral angle between the square plane of 11° compares with 25°, and the rotation of the square planes with respect to each other about the Pt–Pt vector is 25° compared to 23°.

The Pt···Pt distance (2.841 Å) in the cation of **4** is very small for platinum in the oxidation state +2, and it appears to be the shortest for 1-methyluracilato bridged Pt(II) complexes found in the literature[48,52] so far.

The 1-MeU bases are almost planar with the coordinated O(4) atom showing the most significant deviation (0.04 Å) from the best plane. The C(2)–O(2) distance of the ketone group (Table 13) is slightly shorter than that in the free base (1.23 Å). The coordination of the metal atom increases the bite distance O(4)–N(3) from 2.27 Å (free base) to 2.31 Å for the coordinated one. There are significant differences in the angles, however, with an increase in N(3)–C(4)–C(5) (~6°) and a decrease in O(4)–C(4)–C(5) (~6°) and C(2)–N(3)–C(4) (~5°). The decrease of C(2)–N(3)–C(4) is expected, because the removal of an exocyclic group (in this case the proton) reduces the internal ring angle[43,50] as mentioned above. For the free bmik ligand a nearly planar geometry is to be expected. In coordinated form as in the molecular cation of **4** the dihedral angle of the almost planar imidazole rings is observed to be 12° with the ketone groups directed toward each other.

In the crystal structure of **4** no tendency is observed for the dinuclear units to build tetrameric cations or even chains for the same reasons as mentioned for **3**. The shortest distance between two platinum atoms of two adjacent cations is 7.32 Å with the nitrate anions far away from the metal atom so that they do not have any bonding interactions with the platinum. Only two possible hydrogen-bonding distances can be found in the crystal structure of **4** between the water molecules and the nitrate anion (Ow(1)···O(22) = 2.92 Å and Ow(1)···O(23) = 2.88 Å).

Conclusion

As a conclusion, the present investigations strongly indicate that the new highly active cytostatic complexes of the type $[Pt(ligand)Cl_2]$ with ligand being a bis(imidazole) derivative might react in vivo in the same manner as *cis*-DDP. It is to be expected that the bis(imidazole) complexes are affecting the secondary structure of the DNA in the same way as *cis*-DDP by coordinating the same donor sites. However, it is to be expected that for these novel tertiary amine complexes (not capable of forming hydrogen bonds through the coordinating amine groups) differences in the physiological action as compared to *cis*-DDP and its analogs must be present. For example, it is not yet known how the repair mechanism of the DNA influences the activity of these tertiary amine complexes.

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Supplementary Material Available: Tables of non-hydrogen atom anisotropic thermal parameters, complete geometric data, and atomic coordinates and isotropic thermal parameters of the hydrogen atoms (17 pages). Ordering information in given on any current masthead page.

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