The Crystal Structures of 2-(3'-Hydroxypropyl)benzimidazolium Hexa- and Tetrachloroplatinate

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2-(3'-Hydroxypropyl)benzimidazolium (Hhpb) hexa- and tetrachloroplatinate $(C_{10}H_{13}N_2O)_2{\cdot}[PtCl_6]$ **1** and $(C_{10}H_{13}N_2O)_2{\cdot}[PtCl_4]$ **2** were synthesized and their crystal structures determined. Compound **1** is monoclinic, space group $P2_1/n$, $a = 8.800(1)$, $b = 14.389(2)$, $c = 10.264(2)$ Å, $\beta = 98.540(10)^\circ$, $V = 1285.3(3)$ Å^3, $Z = 2$ and $D_c = 1.959$ g cm^{-3}. Compound **2** is triclinic, space group $P1$, $a = 7.8480(10)$, $b = 9.0460(10)$, $c = 9.6980(10)$ Å, $\alpha = 65.420(10)$, $\beta = 68.810(10)$, $\gamma = 76.770(1)^\circ$, $V = 581.26(4)$ Å^3, $Z = 1$ and $D_c = 1.969$ g cm^{-3}. In both compounds, the Pt atoms reside at a centre of inversion. Compounds **1** and **2** are comprised of 2-(3'-hydroxypropyl)benzimidazolium $(Hhpb)^+$: $(C_{10}H_{12}N_2O)^+$ and $[PtCl_6]^{2-}$ and $[PtCl_4]^{2-}$ ions, respectively, linked by intermolecular hydrogen bonds N···Cl [range from 3.428(3) to 3.584(4) Å], N···O [2.769(5) Å] and O···Cl [3.338(4) and 3.321(3) Å] for **1**, and N···Cl [3.162(7) Å], N···O [2.749(8) Å] and O···Cl [3.289(6) Å] for **2**.

Key words: Crystal Structure, Platinate Salts, Benzimidazole, Antitumor Drugs, Hydrogen Bonds

Introduction

Cisplatin [*cis*-$PtCl_2(NH_3)_2$] is one of the most widely used antitumor drugs [1]. Despite the great success in treating certain kinds of cancers, there are several side effects of both intrinsic and acquired resistance. Therefore its clinical utility is restricted by both toxicological and especially tumor resistance considerations [2].

There is continuing interest in the development of new platinum complexes which are less toxic and have a broader spectrum of activity. Variations in the nature of the amine can have a significant effect on the activity and toxicity of the complexes. Several platinum complexes with N-heterocyclic ligands such as imidazol, thiazole, benzimidazole, benzoxazole, and benzothiazole have been reported [3 – 10]. Benzimidazole derivates are known to exhibit a wide variety of pharmacological properties including antitumor activity [11], and some compounds are used as drugs [12].

In previous papers we reported the synthesis, characterization and *in vitro* cytotoxic activities of complexes of the structure *cis*-[Pt(L)$_{1 \text{ or } 2}$Cl$_2$], where L is mono- or bidentate 2-substituted benzimidazole [13, 14]. It was found that some of these new benzimidazole Pt(II) complexes have *in vitro* cytotoxic activities equal to cisplatin.

Even though benzimidazole platinum complexes have been studied extensively, there are only a few reports the on the platinum salts with benzimidazolium cations $[Hhpb]^+$ [15, 17]. In this paper, we report the crystal structures of the salts $(Hhpb)_2{\cdot}[PtCl_6]$ **1** and $(Hhpb)_2{\cdot}[PtCl_4]$ **2**.

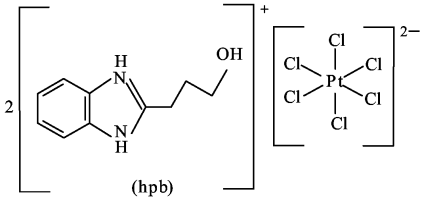
Experimental Section

Preparation of compounds **1** *and* **2**

To a stirred solution of 2-(3'-hydroxypropyl)benzimidazole (0.3 g, 1.703 mmol) in 0.5 N HCl (5 ml) was added dropwise a solution of K_2PtCl_4 (0.404 g, 0.973 mmol) in 0.5 N HCl (5 ml) over 30 min at room temperature. The reaction mixture was protected from light and heated at 60 °C for 5 days, after which time the resulting crude precipitate was filtered off and dissolved in 5 N HCl by heating at 60 °C. The resulting solution was kept at room temperature. After two days, yellow crystals suitable for X-ray diffraction were

Table 1. Crystallographic data and structure refinement.

	1	**2**
Sum formula	$[C_{10}H_{13}N_2O_1]\cdot PtCl_6$	$[C_{10}H_{13}N_2O]\cdot PtCl_4$
Crystal system	monoclinic	triclinic
Space group	$P2_1/n$	$P\bar{1}$
a [Å]	8.800(1)	7.8480(10)
b [Å]	14.389(2)	9.0460(10)
c [Å]	10.264(2)	9.6980(10)
α	90	65.420(10)
β [°]	98.540(10)	68.810(10)
γ	90	76.770(10)
Vol [Å^3]	1285.3(3)	581.26(11)
Z	2	2
D_{calc} [g·cm^{-3}]	1.970	1.975
μ [cm^{-1}]	6.109	6.520
Index ranges	$-12 \le h \le 11$	$-9 \le h \le 10$
	$-20 \le k \le 19$	$-12 \le k \le 9$
	$-12 \le l \le 14$	$-9 \le l \le 13$
Reflections collected	9412	2990
Independent reflections	3509	2945
Data / restraints / parameters	3509/ 0 / 154	2990 / 0 / 144
Final R indices $[I > 2\sigma(I)]$	$R = 0.0261$	$R = 0.0254$
	$wR = 0.0613$	$wR = 0.0567$
Final R indices (all data)	$R = 0.0477$	$R = 0.0282$
	$wR = 0.0783$	$wR = 0.0930$
Goodness-of-fit on F^2	1.088	1.207
Largest diff. peak and hole [e · Å^{-3}]	0.467 and −0.444	0.905 and −1.040



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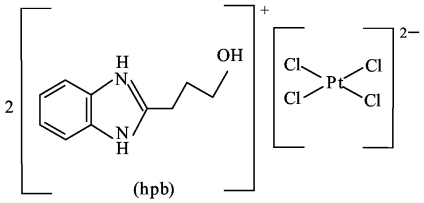

2

obtained by slow evaporation of the solvent at room temperature. The same procedure was used for the syntheses of the compound **2**.

All chemicals and solvents were obtained commercially and used without purification. TLC was performed on precoated aluminium plates (Silicagel 60 F_{254}, Merck). Plates were visualized by UV light, Dragendorff reagent and iodine vapour.

Melting points were measured on an Electrothermal 9200 melting point apparatus and are uncorrected. Elemental analyses were performed by TÜBİTAK Laboratory (Ankara, Türkiye). Infrared (IR) spectra were recorded in KBr pellets and in Nujol mulls on a Mattson 1000 FTIR spectrometry in the range of 4000 – 200 cm^{-1}. For the region 400 – 200 cm^{-1}, the samples were prepared as Nujol mulls on CsI Windows.

Compound **1**: M.p. 219 – 220 °C. Yield: 8% IR: ν = 3470, 3250 – 3100, 1620, 1565, 1040, 322 cm^{-1}. $C_{20}H_{26}Cl_6N_4O_2Pt$ (762.3): calcd. C 31.51, H 3.44, N 7.35; found C 32.05, H 3.58, N 7.37. Compound **2**: M.p. 196.8 °C. Yield: 10% IR: ν = 3398, 3150 – 3040, 1620, 1565, 1040, 320 cm^{-1}. $C_{20}H_{26}Cl_4N_4O_2Pt$ (659.4): calcd. C 36.43, H 3.97, N 8.50; found C 36.84, H 4.08; N 8.56.

Crystal structure determination

Crystals of **1** and **2** were mounted on an Oxford Diffraction Xcalibur CCD diffractometer with graphite monochromatized Mo-K_α radiation (λ = 0.71073 Å). Experimental conditions are summarized in Table 1. Data collection, reduction and corrections for absorption and decomposition were achieved using CrysAlis CCD, CrysAlis RED [18]. The structures were solved by SHELXS-97 and refined with SHELXL-97 [19, 20]. The positions of the H atoms bonded to C atoms were calculated (C-H distance 0.96 Å), and refined using a riding model (except HN1). The hydrogen atoms HN1 riding on the N1 atoms are found from a difference map at the end of the refinement process as a small positive electron density. The H atom displacement parameters were restricted to be 1.2 U_{eq} of the parent atom. Fractional atomic coordinates and equivalent isotropic displacement parameters for non-hydrogen atoms are given in Table 2 for **1**

Table 2. Atomic coordinates and equivalent isotropic displacement parameters [Å^2] of the non-hydrogen atoms for compound **1**.

Atom	*x*	*y*	*z*	*U*(eq)*
C1	0.2656(5)	0.5319(3)	0.9664(4)	0.0343(9)
C2	0.3146(5)	0.6137(3)	0.9130(4)	0.0415(10)
C3	0.4174(5)	0.6672(3)	0.9959(5)	0.0453(11)
C4	0.4707(5)	0.6405(3)	1.1245(5)	0.0445(11)
C5	0.4216(5)	0.5600(3)	1.1769(4)	0.0403(10)
C6	0.3186(5)	0.5060(2)	1.0952(4)	0.0302(8)
C7	0.1536(5)	0.3979(3)	1.0074(4)	0.0394(9)
C8	0.0577(6)	0.3130(4)	0.9943(5)	0.0519(12)
C9	0.1048(5)	0.2420(3)	0.9011(5)	0.0423(10)
C10	0.0096(5)	0.1542(3)	0.9004(5)	0.0519(12)
N1	0.2481(4)	0.4223(2)	1.1157(3)	0.0370(8)
N2	0.1626(4)	0.4624(3)	0.9161(3)	0.0421(8)
O1	−0.1480(3)	0.1719(2)	0.8471(3)	0.0515(8)
Cl1	−0.0149(1)	0.38364(7)	0.3430(1)	0.0420(3)
Cl2	−0.1199(1)	0.40676(8)	0.6383(1)	0.0487(3)
Cl3	0.2338(1)	0.44064(9)	0.5982(1)	0.0466(3)
Pt1	0	1/2	1/2	0.02672(9)

Table 3. Atomic coordinates and equivalent isotropic displacement parameters [Å^2] of the non-hydrogen atoms for compound **2**.

Atom	*x*	*y*	*z*	*U*(*eq*)*
C1	0.7708(7)	−0.0474(7)	0.4852(6)	0.0312(1)
C2	0.8386(9)	−0.1992(7)	0.4751(7)	0.0389(12)
C3	0.8923(9)	−0.3147(8)	0.6031(8)	0.0433(13)
C4	0.8792(9)	−0.2814(8)	0.7343(7)	0.0441(14)
C5	0.8120(9)	−0.1317(8)	0.7443(7)	0.0396(12)
C6	0.7591(7)	−0.0140(7)	0.6161(6)	0.0310(10)
C7	0.6657(7)	0.2127(7)	0.4421(6)	0.0327(11)
C8	0.6008(9)	0.3855(8)	0.3688(7)	0.0414(13)
C9	0.5807(9)	0.4402(8)	0.2037(7)	0.0407(13)
C10	0.5203(9)	0.6206(8)	0.1423(7)	0.0430(13)
N1	0.6923(6)	0.1481(6)	0.5842(5)	0.0330(9)
N2	0.7094(7)	0.0977(6)	0.3806(6)	0.0355(10)
O1	0.3495(6)	0.6584(5)	0.2475(5)	0.0392(9)
Cl1	0.3151(2)	−0.0140(2)	−0.1030(2)	0.0380(3)
Cl2	−0.0164(2)	0.2813(2)	−0.0944(2)	0.0412(3)
Pt1	0	0	0	0.02845(14)

* $U(\mathrm{eq}) = (1/3)\Sigma_i\Sigma_j U_{ij} a_i^* a_j^* a_i a_j$.

and in Table 3 for **2**. Selected bond distances and bond angles are listed in Tables 4 and 5. ORTEP views of the molecular structures are given in Figs 1 and 2 and crystal packing diagrams in Fig. 3 and Fig. 4 [21, 22]. Crystallographic data (excluding structure factors) for the structures have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication no. CCDC-243251 for **1** and CCDC-243250 for **2** [23].

Results and Discussion

The title compounds $(Hhpb)_2{\cdot}[PtCl_6]$ **1** and $(Hhpb)_2{\cdot}[PtCl_4]$ **2** are salts that consist of a octahedral hexachloroplatinate(IV) anion for compound **1** and a square-planar tetrachloroplatimnate(II) anion for compound **2** with hydrogen bonds to ring H atoms on two ($C_{10}H_{13}N_2O$), $(Hhpb)^+$ cations.

In both of the compound **1** and **2**, the Pt atoms reside at a centre of inversion. The average Pt–Cl bond distances are 2.316(1) Å for **1** and 2.306(1) Å for **2**. The bond lengths at the Pt atom can be compared with

Table 4. Selected bond distances [Å] and bond angles [°] with e. s. d. in parentheses for compound **1**.

C1−N2	1.396(6)	C7−N1−C6	109.7(4)
C6−N1	1.386(5)	C7−N2−C1	109.5(4)
C7−N2	1.330(6)	Cl1−Pt1−Cl1^{i}	180
C7−N1	1.332(5)	Cl1−Pt1−Cl3^{i}	90.54(4)
C7−C8	1.480(6)	Cl1−Pt1−Cl3	89.46(4)
C8−C9	1.499(6)	Cl3−Pt1−Cl3^{i}	180
C9−C10	1.516(6)	Cl1−Pt1−Cl2	91.36(4)
C10−O1	1.436(5)	Cl1^{i}−Pt1−Cl2	88.64(4)
Pt1−Cl1	2.314(1)	Cl2−Pt1−Cl2^{i}	180
Pt1−Cl3	2.315(1)	Cl3^{i}−Pt1−Cl2	91.38(5)
Pt1−Cl2	2.318(1)	Cl3−Pt1−Cl2	88.62(4)

^{i}: $[-x, -y+1, -z+1]$.

Table 5. Selected bond distances [Å] and bond angles [°] with e. s. d. in parentheses for compound **2**.

C1−N2	1.393(7)	C7−N1−C6	109.7(4)
C6−N1	1.382(7)	C7−N2−C1	109.5(4)
C7−N2	1.326(7)	Cl1−Pt1−Cl2^{i}	89.33(6)
C7−N1	1.330(7)	Cl1−Pt1−Cl2	90.67(6)
C7−C8	1.476(8)	Cl1−Pt1−Cl1^{i}	180
C8−C9	1.524(8)	Cl2− Pt1−Cl2^{i}	180
C9−C10	1.511(9)		
C10−O1	1.431(7)		
Cl1−Pt1	2.303(1)		
Cl2−Pt1	2.308(1)		

^{i}: $[-x, -y, -z]$.

Table 6. Hydrogen bonding interactions in compounds **1** and **2**. Bond distances [Å] and bond angles [°] with e.s.d. in parentheses.

Hydrogen bonds[a] for **1**[s]				
D	A	H	D···A [Å]	D – H···A [°]
N1	O1^{i}	H1N	2.769(5)	166.6(3)
N2	Cl2	H2a	3.584(4)	155.9(2)
N2	Cl3	H2a	3.428(4)	127.3(2)
N2	Cl1^{ii}	H2a	3.555(4)	129.8(3)
O1	Cl3^{iii}	H1	3.338(4)	154.0(2)
O1	Cl1^{iii}	H1	3.321(3)	126.3(2)

[s] Symmetry code for **1**: [i] $x+1/2, -y+1/2, z+1/2$; [ii] $-x, -y+1, -z+1$; [iii] $x-1/2, -y+1/2, z+1/2$.

Hydrogen bonds[a] for **2**[s]				
D	A	H	D···A [Å]	D – H···A [°]
N1	O1^{i}	H1N	2.749(8)	160.1(3)
N2	Cl1^{ii}	H2a	3.162(7)	153.3(3)
O1	Cl2^{iii}	H1	3.289(6)	178.5(3)

[s] Symmetry code for **2**: [i] $-x+1, -y+1, -z+1$; [ii] $-x+1, -y, -z$; [iii] $-x, -y+1, -z$; [a] (A = acceptor, D = donor atom).

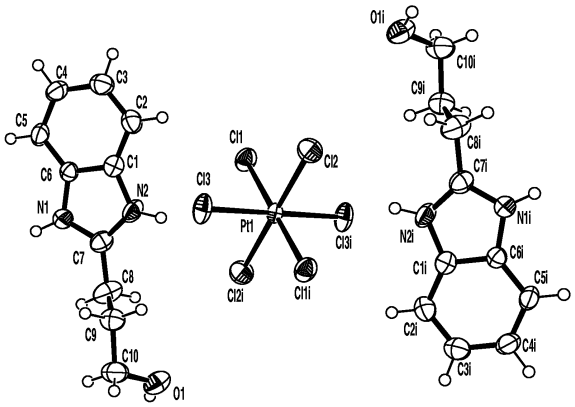

Fig. 1. The molecular structure of compound **1**. Displacement ellipsoids are plotted at the 50% probability level (Symmetry transformations used to generate equivalent atoms (i): $-x$, $-y+1$, $-z+1$).

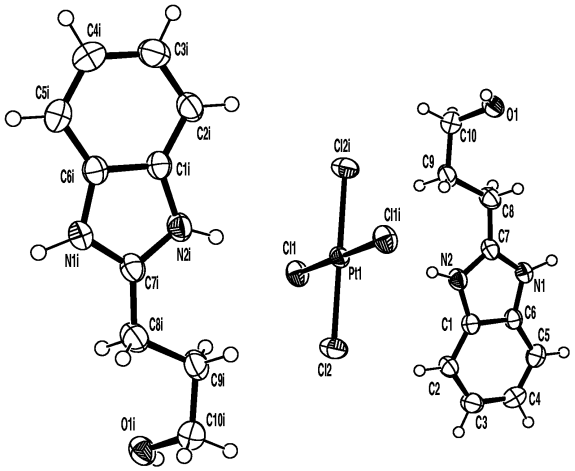

Fig. 2. The molecular structure of compound **2**. Displacement ellipsoids are plotted at the 50% probability level (Symmetry transformations used to generate equivalent atoms (i): $-x$, $-y$, $-z$).

that of 2.314(1) Å in K_2PtCl_6 [24] and 2.323(4) Å in K_2PtCl_6 [23] and 2.324(4) Å in the $[PtCl_6]$ salt [26].

The structures of both compounds consist of discrete $(Hhpb)^+$ cations and $[PtCl_6]^{2-}$ anions for **1** and $[PtCl_4]^{2-}$ anions for **2**. In compound **1**, each $[PtCl_6]^{2-}$ ion is linked to two cations with hydrogen bonds (N–H···Cl) [N2···Cl2 3.584(4) Å, N2···Cl3 3.428(4) Å and N2···Cl1^{ii} 3.555(4) Å, symmetry code: (ii) $-x$, $-y+1$, $-z+1$] and (N–H···O) [N1···O1^{i} 2.769(5) Å symmetry code: (i) $x+1/2$, $-y+1/2$, $-z+1/2$], and (O–H···Cl) [O1···Cl3^{iii} 3.338(4) Å and O1···Cl1^{iii} 3.321(3) Å, symmetry code: (iii) $x-1/2$, $-y+1/2$, $z+1/2$] (Table 6). In compound **2**, each $[PtCl_4]^{2-}$ ion is linked to two cations with hydrogen bonds N2–H···Cl^{ii} 3.162(7) Å, [symmetry code: (ii) $-x+1$, $-y$, $-z$], O1–H···Cl2^{iii} 3.289(6) Å [symmetry code: (iii) $-x$, $-y+1$, $-z$], and [N1–H···O1^{i} 2.749(8) Å, [symmetry code: (ii) $-x+1$, $-y+1$, $-z+1$] (Table 6).

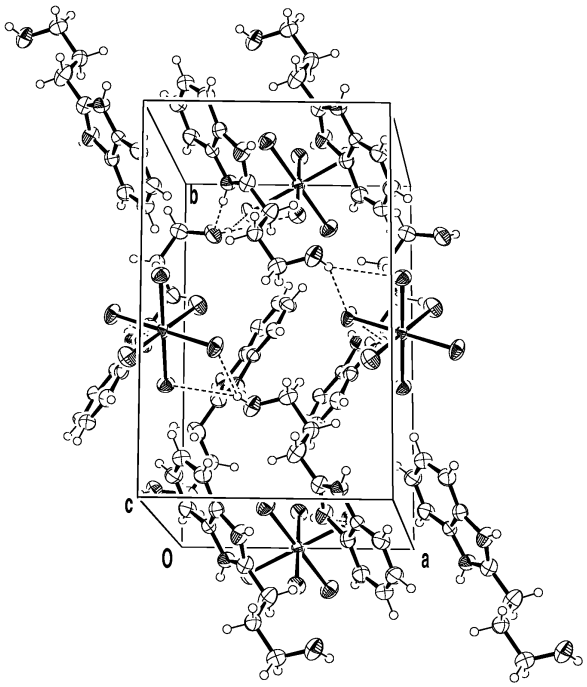

Fig. 3. Unit cell packing diagram for compound **1**. Hydrogen bonding interactions are representing by broken lines.

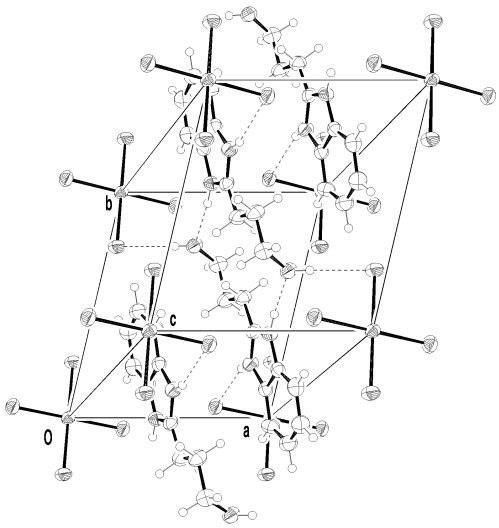

Fig. 4. Unit cell packing diagram for compound **2**. Hydrogen bonding interactions are representing by broken lines.

The molecule packing diagrams for compounds **1** and **2** are shown in Figs 3 and 4 as a projection along the *c*-axis. The relative displacement of adjacent $(Hhpb)^+$ cations of the stack results in a zigzag structure. The interplanar spacing of the π-π stacks are quite different in the two salts. The interplanar spacing of $(Hhpb)^+$ cations are 3.953 and 3.979 Å for **1** and 3.615 and 5.018 Å for **2**. These spacing difference is due to the $[PtCl_6]^{2-}$ and $[PtCl_4]^{2-}$ anions, which are located near the $(Hhpb)^+$ cations, making close hydrogen bonds in both salts. The π-π stacking structures could be the main routes for energy and electron transfer [27]. The anions are important for controlling the π-π interactions.

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