Acta Crystallographica Section C
Crystal Structure Communications
ISSN 0108-2701

(4′-Chloro-2,2′:6′,2″-terpyridine-*N*,*N*′,*N*″)(diethylphosphinothioato-*S*)-platinum(II) tetraphenylborate

Steven A. Ross,[a] Gordon Lowe[a]* and David J. Watkin[b]

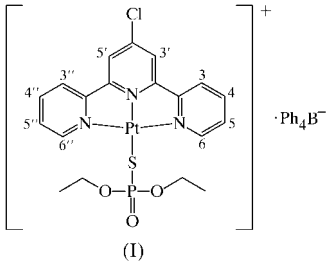
[a]Dyson Perrins Laboratory, University of Oxford, South Parks Road, Oxford OX1 3QY, England, and [b]Chemical Crystallography Laboratory, 9 Parks Road, Oxford OX1 3PD, England
Correspondence e-mail: gordon.lowe@chem.ox.ac.uk

Received 19 September 2000
Accepted 11 December 2000

The title compound, $[Pt(C_4H_{10}O_3PS)(C_{15}H_{10}ClN_3)](C_{24}H_{20}B)$, has a distorted square-planar coordination geometry at the platinum(II) centre, due to the constraints of the tridentate terpyridine ligand. The Pt^{II}-bound diethylphosphinothioate ligand takes up a conformation to avoid non-bonding contacts with atoms H6 and H6″.

Comment

Platinum(II) complexes of 2,2′:6′,2″-terpyridine ligands are of interest due to their photophysical properties (Tzeng *et al.*, 1999), fast ligand-substitution kinetics (Mureinik & Bidani, 1978; Carr *et al.*, 2000), and antitumour (Lowe, Droz, Vilaivan, Weaver, Park *et al.*, 1999) and antiparasitic activity (Lowe, Droz, Vilaivan, Weaver, Tweedale *et al.*, 1999). Intercalation into nucleic acids (McCoubrey *et al.*, 1996) and irreversible enzyme inhibition (Bonse *et al.*, 2000) have been implicated as possible modes of action of this class of compounds *in vivo*. Oligo(deoxy)ribonucleotides containing phosphinothioate linkages have been proposed as potential antisense or antigene agents, due to their resistance to enzymatic hydrolysis *in vivo* (Eckstein, 2000). Binding of platinum complexes to the phosphinothioate linkage of oligonucleotides has been reported by Elmroth & Lippard (1995), and crosslinking of



(I)

oligonucleotides using binuclear platinum complexes has also been reported (Gruff & Orgel, 1991). In addition, phosphinothioates have been used as chemoprotective agents for platinum antitumour agents (Thompson *et al.*, 1995). We describe herein the first single-crystal X-ray structure of a mononuclear platinum(II)–phosphinothioate complex, (I).

The distorted square-planar geometry of the Pt centre in (I) [N5—Pt1—N16 = 161.61 (14)°; Fig. 1] is in agreement with other reported (terpyridine)platinum(II) complexes (Chernega *et al.*, 1996; Jennette *et al.*, 1976; Tzeng *et al.*, 1999). The Pt1—S21—P22 bond angle of 96.84 (5)° is quite acute and is comparable with the equivalent Pt—S—P angles of 107.0 (1) and 104.6 (1)° in a related Pt^{II}–Zn^{II} bridged dialkylphosphinothioate complex reported by Poat *et al.* (1990).

The N5—Pt1—S21—P22 torsion angle of 97.0 (3)° illustrates the necessity for the phosphinothioate ligand to adopt a conformation which avoids non-bonding contacts with atoms H6 and H6″ (H61 and H171 in the present atom-labelling scheme) of the terpyridine ligand. This torsion angle leads to the P centre being displaced significantly from the (terpyridine)platinum(II) plane. Thus, intercalation of this complex into double-stranded nucleic acids would almost certainly lead to steric interactions between the phosphinothioate group and adjacent base pairs. Interestingly, O23 is displaced by 2.58 (2) Å from the mean plane defined by Pt1, N5, N2, N16 and S21, which may facilitate hydrogen-bonding interactions between O23 and the adjacent base pairs of DNA upon intercalation.

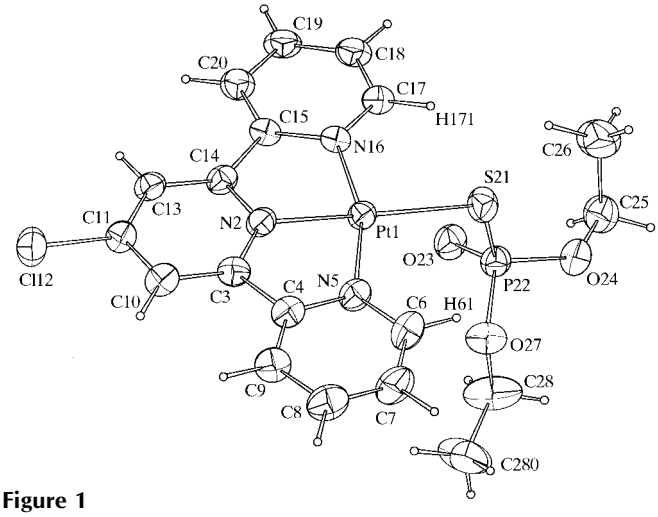


Figure 1
The molecular structure of the cation of (I) with the atom-labelling scheme. Displacement ellipsoids are drawn at the 50% probability level.

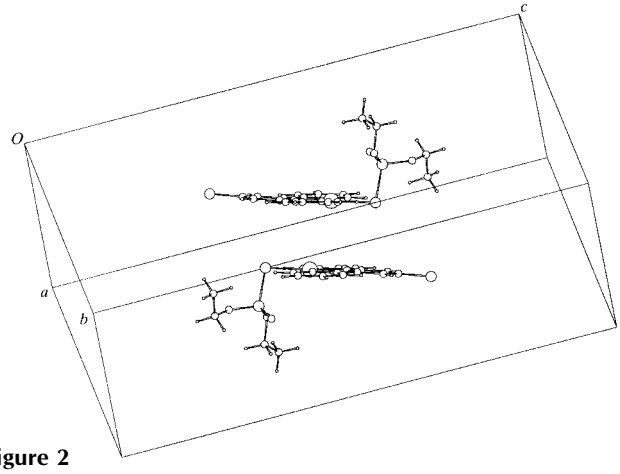


Figure 2
The intermolecular stacking interactions of the cationic units of (I).

The crystal structure of (I) shows that the cations are arranged in a stacked manner in the solid state (Fig. 2). This has been observed previously with (terpyridine)platinum(II) complexes (Chernega *et al.*, 1996; Tzeng *et al.*, 1999), and is a good indication of the ability of these compounds to intercalate and also to stack in solution (Jennette *et al.*, 1976). The intermolecular stacking distance [3.59 (5) Å between the equivalent mean planes described above] and antiparallel orientation are consistent with previously reported structures. The intermolecular Pt1···Pt1′ distance is 4.29 (5) Å.

Finally, the structural parameters for the present platinum(II)–phosphinothioate complex will prove useful in predicting how the (terpyridine)platinum(II) fragment will bind to nucleic acids containing the phosphinothioate linkage.

Experimental

Complex (I) was prepared as its nitrate salt in 71% yield following the general method of Lowe & Vilaivan (1996). Triethylammonium diethylphosphinothioate was prepared as described previously by Reynolds *et al.* (1983). Dissolution of the nitrate salt in water followed by the addition of excess sodium tetraphenylborate afforded a yellow precipitate which was redissolved by the addition of acetonitrile. Evaporation of this water/acetonitrile solution afforded single crystals of (I) (m.p. > 503 K). Spectroscopic analysis: ^{1}H NMR (200 MHz, d_6-DMSO, δ, p.p.m.): 1.12 (6H, *t*), 4.01 (4H, *quin*), 8.02 (2H, *dd*), 8.51 (2H, *dd*), 8.57 (2H, *d*), 9.00 (2H, *s*), 9.23 (2H, *d*); ^{31}P NMR (101 MHz, d_6-DMSO, δ, p.p.m.) 31.93 ($J_{^{195}Pt-^{31}P}$ = 88 Hz); elemental analysis calculated (for hexafluorophosphate salt): C 29.3, H 2.6, N 5.4%; found: C 29.4, H 2.6, N 5.4%.

Crystal data

$[Pt(C_4H_{10}O_3PS)(C_{15}H_{10}ClN_3)](C_{24}H_{20}B)$
M_r = 951.20
Monoclinic, $P2_1/n$
a = 10.7550 (5) Å
b = 13.5230 (3) Å
c = 26.764 (1) Å
β = 87.356 (2)°
V = 3888.4 Å^3
Z = 4
D_x = 1.62 Mg m^{-3}
Mo $K\alpha$ radiation
Cell parameters from 16 185 reflections
θ = 0–27°
μ = 3.82 mm^{-1}
T = 190 K
Prism, yellow
0.8 × 0.2 × 0.2 mm

Data collection

Enraf–Nonius DIP2000 diffractometer
ω scans
Absorption correction: multi-scan (*DENZO*; Otwinowski & Minor, 1997)
T_{min} = 0.46, T_{max} = 0.46
16 185 measured reflections
7838 independent reflections
5773 reflections with $I > 3\sigma(I)$
R_{int} = 0.05
θ_{max} = 26.57°
$h = -13 \rightarrow 13$
$k = 0 \rightarrow 16$
$l = 0 \rightarrow 33$

Refinement

Refinement on F
R = 0.030
wR = 0.037
S = 1.026
5773 reflections
487 parameters
H-atom parameters not refined
Weighting scheme: Chebychev polynomial with 3 parameters (Carruthers & Watkin, 1979): 1.66, 0.505 and 1.28
$(\Delta/\sigma)_{max} < 0.001$
$\Delta\rho_{max}$ = 1.69 e Å^{-3}
$\Delta\rho_{min}$ = −0.84 e Å^{-3}

H atoms were placed geometrically after each cycle. The short C28—C280 bond is probably a consequence of librational disorder, but it could not be reliably modelled on this basis.

Table 1
Selected geometric parameters (Å, °).

Pt1—S21	2.3230 (11)	P22—O24	1.569 (3)
Pt1—N2	1.946 (3)	P22—O27	1.571 (3)
Pt1—N5	2.020 (4)	O24—C25	1.471 (6)
Pt1—N16	2.027 (3)	O27—C28	1.447 (6)
S21—P22	2.0346 (16)	C25—C26	1.479 (8)
P22—O23	1.473 (3)	C28—C280	1.415 (9)
S21—Pt1—N2	178.6 (1)	S21—P22—O24	106.56 (14)
S21—Pt1—N5	99.4 (1)	O23—P22—O24	112.52 (19)
N2—Pt1—N5	80.87 (14)	S21—P22—O27	103.76 (13)
S21—Pt1—N16	98.9 (1)	O23—P22—O27	113.92 (19)
N2—Pt1—N16	80.82 (14)	O24—P22—O27	103.22 (19)
N5—Pt1—N16	161.61 (14)	P22—O24—C25	121.2 (3)
Pt1—S21—P22	96.84 (5)	P22—O27—C28	118.2 (3)
S21—P22—O23	115.69 (15)		

Data collection: *XPRESS* (MacScience, 1989); cell refinement: *DENZO* (Otwinowski & Minor, 1997); data reduction: *DENZO*; program(s) used to solve structure: *SIR*92 (Altomare *et al.*, 1994); program(s) used to refine structure: *CRYSTALS* (Watkin, Prout, Carruthers & Betteridge, 1996); molecular graphics: *CAMERON* (Watkin, Prout & Pearce, 1996); software used to prepare material for publication: *CRYSTALS*.

We thank the EPSRC and BBSRC for support.

Supplementary data for this paper are available from the IUCr electronic archives (Reference: GD1116). Services for accessing these data are described at the back of the journal.

References

Altomare, A., Cascarano, G., Giacovazzo, C., Guagliardi, A., Burla, M. C., Polidori, G. & Camalli, M. (1994). *J. Appl. Cryst.* **27**, 435.
Bonse, S., Richards, J. M., Ross, S. A., Lowe, G. & Krauth-Siegel, R. L. (2000). *J. Med. Chem.* **43**, 4812–4821.
Carr, C. A., Richards, J. M., Ross, S. A. & Lowe, G. (2000). *J. Chem. Res.* (*S*), pp. 566–568.
Carruthers, J. R. & Watkin, D. J. (1979). *Acta Cryst*, A**35**, 698–699.
Chernega, A., Droz, A. S., Prout, K., Vilaivan, T., Weaver, G. W. & Lowe, G. (1996). *J. Chem. Res.* (*S*), pp. 402–403.
Eckstein, F. (2000). *Antisense Nucleic Acid Drug Dev*. **10**, 117–121.
Elmroth, S. K. C. & Lippard, S. J. (1995). *Inorg. Chem.* **34**, 5234–5243.
Gruff, E. S. & Orgel, L. E. (1991). *Nucleic Acids Res.* **19**, 6849–6854.
Jennette, K. W., Gill, J. T., Sadownick, J. A. & Lippard, S. J. (1976). *J. Am. Chem. Soc.* **98**, 6159–6168.
Lowe, G., Droz, A. S., Vilaivan, T., Weaver, G. W., Park, J. J., Pratt, J. M., Tweedale, L. & Kelland, L. R. (1999). *J. Med. Chem.* **42**, 3167–3174.
Lowe, G., Droz, A. S., Vilaivan, T., Weaver, G. W., Tweedale, L., Pratt, J. M., Rock, P., Yardley, V. & Croft, S. L. (1999). *J. Med. Chem.* **42**, 999–1006.
Lowe, G. & Vilaivan, T. (1996). *J. Chem. Res.* (*S*), pp. 386–387.
McCoubrey, A., Latham, H. C., Cook, P. R., Rodger, A. & Lowe, G. (1996). *FEBS Lett.* **380**, 73–78.
MacScience (1989). *XPRESS*. MacScience Co. Ltd, Yokohama, Japan.
Mureinik, R. J. & Bidani, M. (1978). *Inorg. Chim. Acta*, **29**, 37–41.
Otwinowski, Z. & Minor, W. (1997). *Methods Enzymol.* **276**, 307–326.
Poat, J. C., Slawin, A. M. Z., Williams, D. J. & Woollins, J. D. (1990). *J. Chem. Soc. Chem. Commun.* pp. 1036–1038.
Reynolds, M. A., Oppenheimer, N. J. & Kenyon, G. L. (1983). *J. Am. Chem. Soc.* **105**, 6663–6667.
Thompson, D. C., Wyrick, S. D., Holbrook, D. J. & Chaney, S. G. (1995). *Biochem. Pharmacol.* **50**, 1413–1419.
Tzeng, B.-C., Fu, W.-F., Che, C.-M., Chao, H.-Y., Cheung, K.-K. & Peng, S.-M. (1999). *J. Chem. Soc. Dalton Trans.* pp. 1017–1023.
Watkin, D. J., Prout, C. K., Carruthers, J. R. & Betteridge, P. W. (1996). *CRYSTALS*. Issue 10. Chemical Crystallography Laboratory, University of Oxford, England.
Watkin, D. J., Prout, C. K. & Pearce, L. J. (1996). *CAMERON*. Chemical Crystallography Laboratory, University of Oxford, England.