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Synthesis and biological activity of platinum(II) and palladium(II) thiosalicylate complexes with mixed ancillary donor ligands

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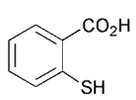
A series of mixed-ligand thiosalicylate complexes of the type [M(SC$_6$H$_4$CO$_2$)(PPh$_3$)L] (M = Pt, L = pyridine (py), 4-methylpyridine, imidazole, 4-picolinic acid hydrazide {C$_5$H$_4$N[C(O)NHNH$_2$]-4}; M = Pd, L = pyridine) have been prepared by the one-pot reaction of [PtCl$_2$(cod)] or [PdCl$_2$(cod)] (cod = cycloocta-1,5-diene) with one equivalent of PPh$_3$ and thiosalicylic acid (HSC$_6$H$_4$CO$_2$H) in the presence of the nitrogen base. Single-crystal X-ray diffraction studies on [Pt(SC$_6$H$_4$CO$_2$)(PPh$_3$)(py)] and the previously reported complex [Pt(SC$_6$H$_4$CO$_2$)(PPh$_3$)(XyNC)] (Xy = 2,6-xylyl) indicates that the complexes have different geometries, though in each case the two ligands of highest *trans*-influence are mutually *cis*. The reaction of [PtCl$_2$(cod)] with PPh$_3$, thiosalicylic acid and ammonia led to the isolation of crystals of the dinuclear thiosalicylate-bridged complex [Pt(SC$_6$H$_4$CO$_2$)(PPh$_3$)(NH$_3$)Pt(SC$_6$H$_4$CO$_2$)(PPh$_3$)], which was characterised by X-ray crystallography and electrospray mass spectrometry. The conformation of the thiosalicylate ligand can vary widely with values for the dihedral angle between the ligand plane and the platinum(II) coordination plane varying from 12.4° to 70.9° in the seven complexes so far determined. The biological activities of selected platinum and palladium thiosalicylate and related complexes against P388 leukemia cells, bacteria and fungi are also reported. The complex [Pt(SCH$_2$CO$_2$)(PPh$_3$)$_2$] shows the highest activity against P388 cells (IC$_{50}$ 671 ng mL^{-1}).

Introduction

Thiosalicylic acid (*o*-sulfanylbenzoic acid) **1** is able to coordinate to metal centres either through its thiolate or carboxylate groups, or both, giving rise to a range of complexes with monodentate, bidentate chelating or bridging thiosalicylate ligands.[1–3] It is also able to coordinate either as a monoanion or dianion. Somewhat surprisingly, the coordination chemistry of this versatile ligand is relatively undeveloped. Recently we reported the synthesis and characterisation of a series of platinum(II), palladium(II) and nickel(II) complexes containing thiosalicylate ligands, **2**.[2] We have also synthesised some organogold(III) thiosalicylate complexes **3**, one of which (**3b**) has potent cytotoxicity towards P388 leukaemia cells.[3] Since gold(III) is isoelectronic (d^8) with platinum(II), we speculated that platinum(II) thiosalicylate complexes might also show high biological activities. In this paper, we describe the synthesis of mixed-ligand platinum(II) thiosalicylate complexes, including the formation of a thiosalicylate-bridged platinum dimer, together with the biological activity of a selection of platinum and palladium thiosalicylate complexes.



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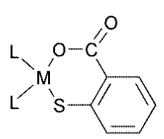
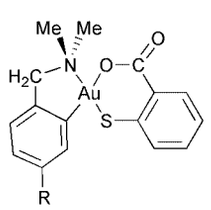


2a, M = Pt, L = PPh$_3$
2b, M = Pt, L = phosphatriazaadamantane (pta)
2c, M = Pt, L$_2$ = Ph$_2$PCH$_2$CH$_2$PPh$_2$
2d, M = Pd, L = PPh$_3$

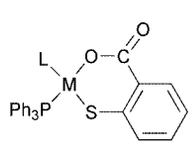


3a; R = H
3b; R = OMe

Results and discussion

Syntheses

Addition of one equivalent of PPh$_3$ to the complex [PtCl$_2$(cod)] (cod = cycloocta-1,5-diene) in methanol, followed by one equivalent of **1** and excess pyridine (py), 4-methylpyridine (Mepy), 4-picolinic acid hydrazide {C$_5$H$_4$N[C(O)NHNH$_2$]-4} (pic) or imidazole (imid) gives the bright yellow mixed-ligand complexes **4** after refluxing, concentrating the solution, and cooling. Similarly, reaction of [PdCl$_2$(cod)] with PPh$_3$, thiosalicylic acid and pyridine gave orange crystals of **4e**. All complexes are air-stable and soluble in polar organic solvents such as chloroform, dichloromethane, *etc*. It is worth noting that pyridine is unable to displace a coordinated triphenylphosphine



4a, M = Pt, L = pyridine (py)
4b, M = Pt, L = 4-methylpyridine (Mepy)
4c, M = Pt, L = picolinic acid hydrazide (pic)
4d, M = Pt, L = imidazole (imid)
4e, M = Pd, L = pyridine

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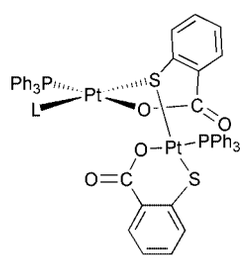
ligand from **2a** since the original synthesis[2] of this complex from *cis*-$[PtCl_2(PPh_3)_2]$ and thiosalicylic acid used excess pyridine (as a base), under comparable reaction conditions.

In an attempt to prepare an analogous complex with triphenylphosphine and ammonia ligands, the reaction of $[PtCl_2(cod)]$ with one equivalent each of **1** and PPh_3, and excess ammonia in refluxing methanol was investigated, and gave a yellow solution. Electrospray mass spectrometry (ESMS) in MeCN–H_2O showed the ion $[Pt(SC_6H_4CO_2)(PPh_3)_2 + H]^+$, with $[Pt(SC_6H_4CO_2)(PPh_3)(NH_3) + H]^+$, $[Pt(SC_6H_4CO_2)(PPh_3)(MeCN) + H]^+$ (*m*/*z* 651) and some of the dinuclear species $[Pt_2(SC_6H_4CO_2)_2(PPh_3)_2(NH_3) + H]^+$ (*m*/*z* 1236). The solution was filtered to remove a small amount of insoluble material, and after standing the filtrate for 5 weeks a small number of yellow crystals were deposited, which were poorly soluble in many common solvents. The crystals were subsequently characterised by an X-ray diffraction study (and confirmed by ESMS) to be the dimeric thiosalicylate-bridged complex **5**.

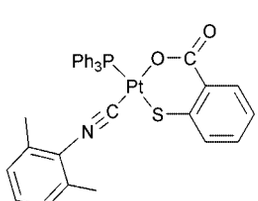


5, L = NH_3
6, L = PPh_3

Attempts to synthesise the triphenylphosphine analogue of **5**, *i.e.* $[Pt_2(SC_6H_4CO_2)_2(PPh_3)_3]$ **6** have not been successful, though the complex can be detected in some reactions by ESMS as its $[M + H]^+$ ion at *m*/*z* 1481. For example, the species **6** has been observed as a minor ion in some syntheses of the complex $[Pt(SC_6H_4CO_2)(PPh_3)_2]$, but reaction of a 2:3:2 stoichiometric ratio of $[PtCl_2(cod)]$, PPh_3 and thiosalicylic acid in refluxing MeOH with Et_3N base for 2 days, followed by concentration of the yellow solution gave $[Pt(SC_6H_4CO_2)(PPh_3)_2]$ **2a** as the only isolated species.

Crystal structures of $[Pt(SC_6H_4CO_2)(PPh_3)(py)]$ 4a and $[Pt(SC_6H_4CO_2)(PPh_3)(XyNC)]$ 7

In order to determine the molecular geometry of complex **4a**, and to compare it with other platinum(II) and gold(III) thiosalicylate complexes, a single-crystal X-ray diffraction study was carried out. For comparative purposes, the structure of the 2,6-xylyl isocyanide (XyNC) complex **7** was also determined.



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The latter complex was previously prepared by reaction of the bis(triphenylphosphine) complex **2a** with XyNC.[2] The molecular structure of **4a** is given in Fig. 1, together with the atom numbering scheme, and selected bond lengths and angles are given in Table 1. Complex **7** crystallises as an acetone solvate with two independent molecules in the asymmetric unit. The molecular structure and atom numbering scheme of molecule 2 of complex **7** is shown in Fig. 2, and selected bond lengths and angles are summarised in Table 2. To the best of our knowledge, complex **4a** is the first structure of a platinum compound containing the N, P, S, O donor atom set.

Both complexes contain the expected square-planar platinum(II) centre and a chelating thiosalicylate dianion ligand.

Table 1 Selected bond lengths (Å) and angles (°) for $[Pt(SC_6H_4CO_2)(PPh_3)(py)]\cdot H_2O$ **4a**·H_2O with estimated standard deviations in parentheses

Platinum co-ordination			
Pt(1)–S(1)	2.255(3)	Pt(1)–N(1A)	2.14(2)
Pt(1)–O(1)	2.054(9)	Pt(1)–P(1)	2.231(3)
Pt(1)–N(1)	2.10(2)		
S(1)–Pt(1)–O(1)	94.0(3)	O(1)–Pt(1)–N(1A)	79.7(6)
N(1)–Pt(1)–P(1)	89.9(5)	S(1)–Pt(1)–P(1)	88.11(12)
N(1A)–Pt(1)–P(1)	97.4(6)	Pt(1)–S(1)–C(1)	109.9(4)
O(1)–Pt(1)–N(1)	89.1(6)	Pt(1)–O(1)–C(7)	134.2(9)
Thiosalicylate ligand			
S(1)–C(1)	1.757(13)	C(7)–C(2)	1.50(2)
C(7)–O(1)	1.28(2)	S(1)···O(1)	3.153
C(7)–O(2)	1.23(2)		
S(1)–C(1)–C(2)	129.3(10)	C(2)–C(7)–O(1)	122.9(13)
C(1)–C(2)–C(7)	126.5(13)	O(2)–C(7)–O(1)	118.0(14)
C(2)–C(7)–O(2)	118.8(14)		

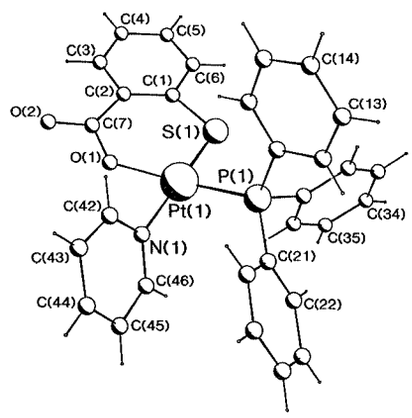


Fig. 1 Molecular structure of $[Pt(SC_6H_4CO_2)(PPh_3)(py)]$ **4a**, showing the atom numbering scheme. Only one position of the disordered pyridine ligand [incorporating nitrogen N(1)] is shown, and the water of crystallisation is omitted.

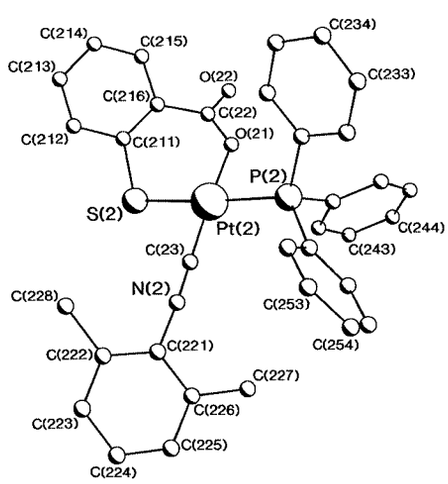


Fig. 2 Molecular structure and atom numbering scheme for molecule 2 of $[Pt(SC_6H_4CO_2)(PPh_3)(XyNC)]$ **7**. The acetone of crystallisation is omitted.

Table 2 Selected bond lengths (Å) and angles (°) for [Pt(SC$_6$H$_4$CO$_2$)(PPh$_3$)(XyNC)]·Me$_2$CO **7**·Me$_2$CO[a]

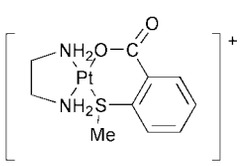
	Molecule 1	Molecule 2
Platinum coordination		
Pt–S	2.3490(8)	2.3395(9)
Pt–O(1)	2.024(2)	2.057(2)
Pt–C(3)	1.883(3)	1.892(3)
Pt–P	2.3068(8)	2.2962(8)
S–Pt–O(1)	87.57(6)	90.63(6)
P–Pt–C(3)	96.06(9)	94.84(9)
O(1)–Pt–P	86.45(6)	85.44(6)
S–Pt–C(3)	90.5(1)	89.2(1)
Pt–S–C(11)	95.0(1)	102.9(1)
Pt–O(1)–C(2)	125.5(2)	131.7(2)
Thiosalicylate ligand		
S–C(11)	1.782(3)	1.782(3)
C(2)–O(1)	1.299(4)	1.277(4)
C(2)–O(2)	1.225(4)	1.238(4)
C(2)–C(16)	1.511(5)	1.484(5)
S···O(1)	3.036(2)	3.132(2)
S(2)–C(11)–C(16)	123.4(3)	125.5(3)
C(11)–C(16)–C(2)	123.5(3)	125.4(3)
C(16)–C(2)–O(2)	119.2(3)	119.3(3)
C(16)–C(2)–O(1)	119.7(3)	122.3(3)
O(2)–C(2)–O(1)	121.1(3)	118.3(3)

[a] Parameters are given for the two independent molecules in the asymmetric unit. Labelling is such that, for example, S refers to S(1) and S(2), and C(11) refers to C(111) and C(211), respectively in molecules 1 and 2.

However, the complexes have different arrangements of ligands; **4a** has the PPh_3 ligand *cis* to the S atom and *trans* to O, while the isocyanide complex **7** has the PPh_3 ligand *trans* to S and *cis* to O. In both cases, the two ligand donor atoms of highest *trans*-influence (P and S in **4a**, P and C in **7**) are *cis* to each other, as is also the case for the gold(III) thiosalicylate complexes **3**.[3] This effect, antisymbiosis, has been well documented.[4]

It is of interest to compare the structures of **4a** and **7** with that of the bis(triphenylphosphine) complex **2a**. Complexes **2a** and **7** have the S atom *trans* to a high *trans*-influence PPh_3 ligand, and so have similar Pt–S bond distances [**2a**, 2.322(2); **7**, 2.3395(8) Å in molecule 2]. In contrast, the S atom in **4a** is *trans* to a much lower *trans*-influence pyridine ligand, so the Pt–S bond is shorter [2.255(3) Å]. Similarly the Pt–P bond distances in **4a** [*trans* to O, 2.231(3) Å] and in **7** [*trans* to S, 2.2962(8) Å in molecule 2] reflect the higher *trans*-influence of the thiolate ligand compared to carboxylate, as is also seen in **2a**. The two bonds *cis* to the pyridine ligand in **4a**, Pt(1)–P(1) and Pt(1)–O(1) are also shortened relative to the corresponding bonds in **2a**. This is presumably because of the small size of pyridine compared to PPh_3, permitting a closer approach of the PPh_3 and carboxylate groups. Thus, in **2a**, the P(1)–Pt and O(1)–Pt bond lengths are 2.2501(11) and 2.109(3) Å, while the P(1)–Pt(1) and O(1)–Pt(1) distances in **4a** are 2.231(3) and 2.054(9) Å respectively.

The Pt–N bond involving the disordered pyridine ligand in **4a** [2.12(2) Å] is longer than the Pt–N bonds *trans* to sulfur found in **8** [2.055(8) Å],[5] though the SMe group is expected to have a lower *trans*-influence which may account for the bond



8

Table 3 Selected bond lengths (Å) and angles (°) for [Pt$_2$(SC$_6$H$_4$CO$_2$)$_2$(PPh$_3$)$_2$(NH$_3$)]·1.5MeOH **5**·1.5MeOH with estimated standard deviations in parentheses

Platinum(1) co-ordination			
Pt(1)–S(1)	2.3068(19)	Pt(1)–S(2)	2.3595(17)
Pt(1)–O(11)	2.068(5)	Pt(1)–P(1)	2.2124(17)
S(1)–Pt(1)–O(11)	84.69(15)	S(1)–Pt(1)–P(1)	89.14(7)
S(2)–Pt(1)–P(1)	97.04(6)	Pt(1)–S(1)–C(11)	97.0(3)
O(11)–Pt(1)–S(2)	89.11(14)	Pt(1)–O(11)–C(17)	126.9(5)
Thiosalicylate ligand(1)			
S(1)–C(11)	1.751(9)	C(17)–O(12)	1.249(9)
C(17)–O(11)	1.270(9)	C(17)–C(16)	1.509(11)
S(1)–C(11)–C(16)	124.6(6)	C(16)–C(17)–O(11)	121.0(7)
C(11)–C(16)–C(17)	121.9(7)	O(12)–C(17)–O(11)	121.4(7)
C(16)–C(17)–O(12)	117.6(7)		
Platinum(2) co-ordination			
Pt(2)–S(2)	2.2799(17)	Pt(2)–N(1)	2.055(6)
Pt(2)–O(21)	2.061(4)	Pt(2)–P(2)	2.2096(17)
S(2)–Pt(2)–O(21)	90.98(14)	S(2)–Pt(2)–P(2)	88.98(6)
N(1)–Pt(2)–P(2)	97.1(2)	Pt(2)–S(2)–C(21)	100.7(2)
O(21)–Pt(2)–N(1)	82.8(2)	Pt(2)–O(21)–C(27)	130.7(4)
Bridging thiosalicylate ligand(2)			
S(2)–C(21)	1.785(7)	O(22)–C(27)	1.225(8)
O(21)–C(27)	1.299(8)	C(26)–C(27)	1.504(10)
S(2)–C(21)–C(26)	124.2(5)	C(26)–C(27)–O(21)	120.3(6)
C(21)–C(26)–C(27)	126.3(6)	O(22)–C(27)–O(21)	120.9(6)
C(26)–C(27)–O(22)	118.7(6)		

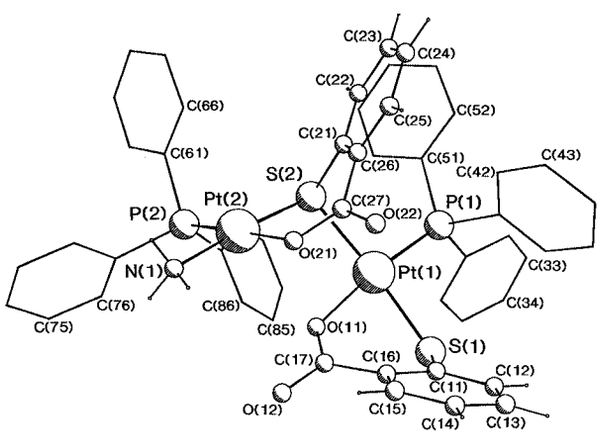


Fig. 3 Perspective view of the molecular structure and atom numbering scheme for [Pt$_2$(SC$_6$H$_4$CO$_2$)$_2$(PPh$_3$)$_2$(NH$_3$)] **5**. The methanol of crystallisation has been omitted.

length difference. The pyridine ligand of **4a** is inclined at an angle of 70.5° to the platinum coordination plane. The structure of **4a** was found to contain one disordered water of crystallisation, H-bonded to the free O(2) of the carboxylate ligand. The conformation of the thiosalicylate ligand is discussed below.

Orange crystals of the palladium complex **4e** (obtained from a saturated methanol solution) were examined by precession photography, and found to be isomorphous with the analogous platinum complex **4a**. The palladium complex is therefore assumed to have the same geometry as the platinum one, with mutually *cis* PPh_3 and thiolate ligands.

Crystal structure of [Pt$_2$(SC$_6$H$_4$CO$_2$)$_2$(PPh$_3$)$_2$(NH$_3$)] 5

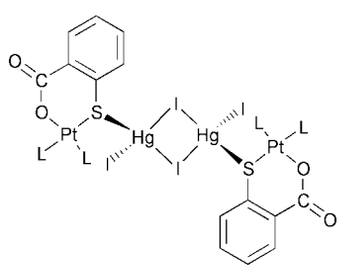
The molecular structure of **5** is shown in Fig. 3, together with the atom numbering scheme. Selected bond lengths and angles are given in Table 3. The complex can be viewed as the mononuclear species [Pt(SC$_6$H$_4$CO$_2$)(PPh$_3$)(NH$_3$)] which has

Table 4 A comparison of bond parameters for Pt(II) thiosalicylate complexes

Compound	Fold angle[a]/°	Twist angle[b]/°	Pt–S/Å	Pt–O/Å	S···O/Å	Pt–S–C/°	Pt–O–C/°	S–Pt–O/°
7 (molecule 1)	70.9	38.4	2.349	2.024	3.035	95.0	125.5	87.6
5 (Pt(2))	66.1	31.8	2.307	2.068	2.952	97.0	126.9	84.7
9	60.5	20.0	2.316	2.076	2.99	99.2	126.0	85.6
5 (Pt(1))	49.3	29.1	2.280	2.061	3.099	100.6	130.7	91.0
2a	47.2	21.1	2.322	2.109	2.99	103.7	135.8	84.7
7 (molecule 2)	40.3	32.7	2.340	2.057	3.132	102.9	131.7	90.6
4a	12.4	4.4	2.255	2.054	3.153	109.9	134.2	94.0

[a] The dihedral angle between the plane of the thiosalicylate ligand (excluding the oxygen atoms) and the Pt(II) coordination plane. [b] The dihedral angle between the plane of the carboxylate group and that of the rest of the ligand.

coordinated its thiolate sulfur to a $[Pt(SC_6H_4CO_2)(PPh_3)]$ moiety. Thiolate-bridged platinum(II) complexes are very well-known[6] but few compounds containing a single thiolate bridge between two metal centres have been reported.[7] However, complexes containing thiosalicylate ligands which bridge through their S atoms are known, *e.g.* the manganese dimer $[(CO)_3Mn(SC_6H_4CO_2)_2Mn(CO)_3]^{2-}$,[8] and complex **9** which contains two



9, L = PPh_3

$[Pt(SC_6H_4CO_2)(PPh_3)_2]$ molecules coordinated to a $IHg(\mu\text{-}I)_2HgI$ unit.[9]

Both platinum centres of **5** have the thiosalicylate sulfur atoms *cis* to the PPh_3 ligand, the same as the pyridine derivative **4a**, and both PPh_3 ligands are *trans* to carboxylate oxygens, with similar bond lengths [Pt(1)–P(1) 2.2124(17), Pt(2)–P(2) 2.2096(17) Å; Pt(1)–O(11) 2.068(5), Pt(2)–O(21) 2.061(4) Å]. The two platinum coordination planes are inclined at an angle of 67.3°.

The bridging thiolate is not symmetrically bonded to both platinum centres, with Pt(1)–S(2) [2.3595(17) Å] somewhat longer than Pt(2)–S(2) [2.2799(17) Å] and Pt(1)–S(1) [2.3068(19) Å], indicating primary coordination of this thiosalicylate ligand in S,O chelate fashion to Pt(2). The Pt(2)–S(2) bond [2.2799(17) Å] is shorter than the corresponding bond in **9** [2.3159(14) Å], where the S is *trans* to a (high *trans*-influence) PPh_3 ligand, compared to a low *trans*-influence NH_3 in **5**. The Pt(2)–S(2)–C(21) and Pt(1)–S(2)–C(21) bond angles of **5** [100.7(2) and 107.5(2)° respectively] are similar to the corresponding Pt–S–C and Pt–S–Hg bond angles [99.2(2) and 105.78(18)°] in **9**, but the Pt(2)–S(2)–Pt(1) bond angle [104.77(7)°] is wider than the Pt–S–Hg angle [96.51(5)°].

With the structures reported here, there are now seven distinct examples of Pt(II)–thiosalicylate complexes for which parameters are determined. It is immediately apparent that the conformation of the thiosalicylate ligand varies widely within this set, as indicated by the dihedral angles between the ligand and coordination planes. In Table 4 are summarised the relevant details.

The "fold angle" between the plane defined by the ligand (excluding the oxygen atoms) and the Pt(II) coordination plane varies from 12.4° in **4a** to 70.9° in one of the independent molecules of **7**. It is clear that this folding is flexible, since the two independent molecules of **7** have dihedral angles of 40.3° and 70.9°, showing that the crystal packing effects can induce large changes. The relative conformation has little effect on the Pt–S (2.31 ± 0.05 Å), Pt–O (2.07 ± 0.04 Å) and S···O (3.05 ± 0.10 Å) distances which remain reasonably constant given the different co-ligands present. (Surprisingly, further coordination of the sulfur atom to another metal, as in **5** or **9**, has little consequence for the chelation interaction with Pt(II).)

The increase in the fold angle is accommodated by a twisting of the carboxylate group out of the plane of the rest of the thiosalicylate ligand (by 4–38°), and leads to a decrease in the Pt–S–C (109.9 to 95.0°) and Pt–O–C (134.2–125.5°) angles. Increased folding also correlates with a decrease in the S–Pt–O angle, although this relationship is less regular. A nickel complex related to **2a** also falls into this general pattern.[2]

The overall picture of the thiosalicylate ligand is therefore one of a relatively rigid unit with a constant S···O bite distance, which can however be readily folded about the S and O chelating atoms by other interactions, either intra- or intermolecular. Changes in conformation and metal size are accommodated mainly by variations in the angles at the chelating S and O atoms.

NMR spectroscopic analysis

$^{31}P\text{-}\{^1H\}$ NMR spectroscopy of the platinum complexes **4** gives a single resonance with ^{195}Pt satellites, with $^1J(PtP)$ values in the range 4146–4201 Hz, showing that the isomer formed in each case has the phosphine ligand *trans* to the carboxylate. By comparison, $^1J(PtP)$ for the PPh_3 *trans* to carboxylate for **2a** is 3899 Hz; the low *cis*-influence of the nitrogen ligands is presumably responsible. Values of $^1J(PtP)$ for phosphines *trans* to thiolate ligands are of the order of 3000 Hz, *e.g.* 3047 Hz for $[Pt(SPh)_2(Ph_2PCH_2CH_2PPh_2)]$[10] and 2884 Hz for the phosphine *trans* to S in **2a**.[2]

The ^{31}P NMR spectra of several batches of the palladium complex **4e** always showed (in addition to the major product at δ 34.9) a small singlet at δ 26.7, which may be the other isomer having the PPh_3 ligand *trans* to sulfur. Consistent with this, excellent microanalytical data were obtained for this complex. Furthermore, for the bis(triphenylphosphine) palladium complex **2d**, the PPh_3 ligand *trans* to S has a higher chemical shift (δ 36.5), similar to the major peak observed for **4e**, while the PPh_3 *trans* to O has a lower chemical shift (δ 25.2), similar to the minor peak observed for **4e** at δ 26.7.[2]

The $^{13}C\text{-}\{^1H\}$ NMR spectrum of **4a** shows a singlet resonance for the coordinated carboxylate at δ 169.4. Complex **2a** also displayed a broadened singlet at δ 168.0,[2] indicating that phosphorus coupling is small.

Electrospray mass spectrometry (ESMS)

ESMS is becoming a routine technique for the characterisation of coordination complexes,[11] and can provide information on fragmentation processes, by the use of high cone voltages. We have described the use of ESMS in characterisation of the thiosalicylate complexes of Ni, Pd and Pt,[2] and of Au.[3] The ease of fragmentation of these complexes is highly dependent on the nature of the ancillary ligands. Thus the organogold(III)

Table 5 Selected electrospray mass spectrometric data for the mixed-ligand thiosalicylate complexes in MeCN–H_2O (1 : 1 v/v)

Complex	Ion mode	Cone voltage/V	Ions (*m/z*, %)[b]
4a	Positive	20	$[M + H]^+$ (689, 100), $[2M + H]^+$ (1377, 73)
		80	$[M + H - py]^+$ (610, 28), $[M + H - py + MeCN]^+$ (651, 12), $[M + H]^+$ (689, 100), $[2M + H - 2py]^+$ (1219, 28), $[2M + H - py]^+$ (1298, 32), $[2M + H]^+$ (1377, 100)
4b	Positive	20	$[M + H]^+$ (703, 100), $[2M + H]^+$ (1405, 68)
		60	$[M + H - (Mepy)]^+$ (610, 68), $[M + H - (Mepy) + MeCN]^+$ (651, 20), $[M + H]^+$ (703, 43), $[2M + H - (Mepy)]^+$ (1313, 20), $[2M + H]^+$ (1405, 100)
4c	Positive	20	$[M + H]^+$ (747, 100), $[2M + H]^+$ (1493, 40)
4d	Positive	20	$[M + H]^+$ (678, 100), $[2M + H]^+$ (1355, 25)
4e	Positive	20	$[M + H]^+$ (600, 100), $[2M + H - py]^+$ (1122, 50), $[2M + H]^+$ (1201, 20)
5[a]	Positive	40	$[M + H]^+$ (1236, 100), $[M + NH_4]^+$ (1253, 45), $[3M + NH_4 + Na]^{2+}$ (1874, 80), $[2M + NH_4]^+$ (2489, 60)
	Negative	60	$[Pt(SC_6H_4CO_2)(PPh_3)Cl]^-$ (645, 70), $[Pt(SC_6H_4CO_2)(PPh_3)(MeOH)Cl]^-$ (677, 30), $[M - PPh_3 - NH_3 + Cl]^-$ (991, 40), $[M - NH_3 + Cl]^-$ (1254, 100)

[a] Sample dissolved in CH_2Cl_2 and analysed with methanol. [b] *m/z* values refer to the most intense peak in the isotope distribution pattern.

complexes, containing two chelate ring systems, are highly resistant towards fragmentation, and the parent $[M + H]^+$ ion was the base peak even at a cone voltage of 200 V. In contrast, complexes containing PPh_3 ligands fragment by means of a cyclometallation process. Thus, it was of interest to examine the mixed-ligand complexes described herein, which contain a relatively weakly coordinated nitrogen-donor ligand, which is expected to be easily lost at elevated cone voltages.

Positive-ion ESMS data for the complexes reported in this paper are given in Table 5. At a relatively low cone voltage (20 V) the platinum complex **4a** yields the expected strong pseudo-parent $[M + H]^+$ ion (*m/z* 689), together with an aggregate ion $[2M + H]^+$ (*m/z* 1377); such behaviour is typical for this class of complex and is observed for **4b**–**4d** and other platinum, palladium and nickel thiosalicylate complexes reported previously.[2] On increasing the cone voltage above 40 V, pyridine is lost preferentially, resulting in the formation of ions $[M + H - py]^+$, $[2M + H - py]^+$, $[2M + H - 2py]^+$ and the solvated analogue $[M + H - py + MeCN]^+$. It is noteworthy that there are no ions containing two platinum atoms together with MeCN, corresponding to the mono-platinum ion $[M + H - py + MeCN]^+$, possibly suggesting the presence of bridging thiosalicylate ligands which would block any vacant coordination sites. The palladium complex **4e** showed similar behaviour, except for the presence of a reasonably intense ion $[2M + H - py]^+$, formed by loss of pyridine, and which could contain a bridging thiosalicylate ligand, analogous to **5** and **6**. The higher lability of palladium compared to platinum complexes might account for this difference.

The dinuclear complex **5** was poorly soluble in methanol and 1 : 1 MeCN–H_2O, but can be successfully analysed by dissolving a few small crystals of the complex in CH_2Cl_2 before diluting with methanol, using pure methanol mobile phase in the spectrometer. The spectra are consistent with the dinuclear nature of the complex (Fig. 4). The positive ion spectrum at 20 V shows a number of ions, all consistent with the dinuclear complex (M) remaining intact: $[M + H]^+$ (*m/z* 1236), $[M + NH_4]^+$ (*m/z* 1253), $[3M + NH_4 + Na]^{2+}$ (*m/z* 1874), and $[2M + NH_4]^+$ (*m/z* 2489). Confirmation of the *m/z* 1874 ion as a dication was readily obtained from the isotope pattern. Increasing the cone voltage to 40 V increased the intensity of the $[M + H]^+$ ion at the expense of the aggregate ions, while at 60 V, fragmentation of the parent begins to occur, with observation of $[M + H - NH_3]^+$ (*m/z* 1219) and $[2M - 2NH_3 + MeOH + H]^+$ (*m/z* 2470). Addition of KCl to the solution of **5** resulted in the observation of analogous potassiated ions, *viz.* $[M + K]^+$ (*m/z* 1274), $[3M + K + H]^{2+}$ (*m/z* 1874), $[3M + 2K]^{2+}$ (*m/z* 1893), and $[2M + K]^+$ (*m/z* 2511), lending additional support to the ion assignments. However, interestingly, addition of $NH_4[HCO_2]$ to the solution only resulted in increasing the intensity of the $[M + H]^+$ (*m/z* 1236) ion, such that few other

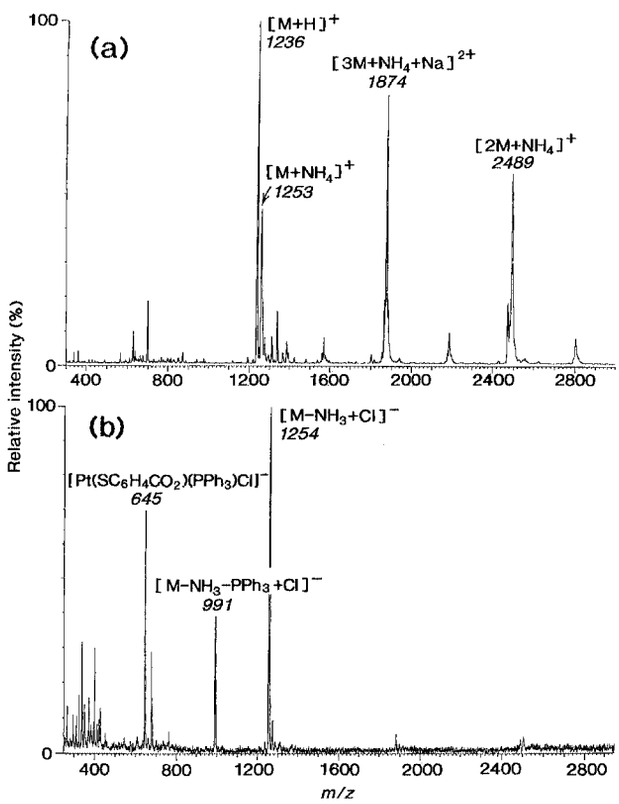


Fig. 4 Electrospray mass spectra of the dinuclear complex $[Pt_2(SC_6H_4CO_2)_2(PPh_3)_2(NH_3)]$ **5** (= M) in CH_2Cl_2–MeOH: (a) positive ion, cone voltage 40 V and (b) negative ion, cone voltage 60 V, showing ion assignments.

ions were observed. At 80 V, the same loss of NH_3 is observed, giving $[M + H - NH_3]^+$ (*m/z* 1219). Analysis of **5** in the more strongly coordinating MeCN–H_2O solvent at cone voltages in the range 20–50 V showed the $[M + H]^+$ ion (*m/z* 1236), together with an ion at *m/z* 651, assigned as $[Pt(SC_6H_4CO_2)(PPh_3)(MeCN) + H]^+$, and a weak ion at *m/z* 627 assigned as $[Pt(SC_6H_4CO_2)(PPh_3)(NH_3) + H]^+$. These ions are presumably formed by cleavage of the thiolate bridge by the solvent MeCN, giving the two mononuclear species.

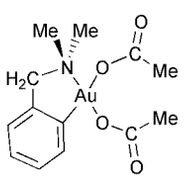
Complex **5** also gives reasonably strong ions in negative ion mode, with $[M - NH_3 + Cl]^-$ (*m/z* 1254) being the base peak at a cone voltage of 20 V, together with the lower intensity ion $[Pt(SC_6H_4CO_2)(PPh_3)Cl]^-$ (*m/z* 645), formed from adventitious chloride ions. Increasing the cone voltage to 60 V effects further fragmentation, with $[Pt(SC_6H_4CO_2)(PPh_3)Cl]^-$ increasing in intensity relative to the base peak of $[M - NH_3 + Cl]^-$, and observation of $[M - NH_3 - PPh_3 + Cl]^-$ (*m/z* 991), and

Table 6 Antitumour (P388), antiviral/cytotoxicity assay results and antimicrobial/antifungal[c] activities[d] for platinum(II) and palladium(II) thiosalicylate and related complexes

Compound	IC_{50}[a]	Cyt[b]	Ec	Bs	Pa	Ca	Tm	Cr
$[Pt(SC_6H_4CO_2)(PPh_3)_2]$ **2a**[g]	2506	4+	12	15	9	13	18	24
$[Pt(SC_6H_4CO_2)(pta)_2]$ **2b**[g]	49680	2+	2	7	—	—	—	—
$[Pt(SC_6H_4CO_2)(dppe)]$ **2c**[g]	799	ND	—	—	—	—	—	—
$[Pd(SC_6H_4CO_2)(PPh_3)_2]$ **2d**[g]	2506	+	—	1	—	—	—	—
$[Pt(SC_6H_4CO_2)(PPh_3)(py)]$ **4a**	1294	3+	1	7	—	—	—	—
$[Pt(SC_6H_4CO_2)(PPh_3)(pic)]$ **4c**	>62500	[f]	[f]	[f]	[f]	[f]	[f]	[f]
$[Pt(SC_6H_4CO_2)(PPh_3)(imid)]$ **4d**	8653	[f]	[f]	[f]	[f]	[f]	[f]	[f]
$[Pd(SC_6H_4CO_2)(PPh_3)(py)]$ **4e**	11483	+−	—	2	—	—	—	—
$[Pt(OC_6H_4CO_2)(PPh_3)_2]$ **12**[g]	6291	ND	—	5	—	1	4	—
$[Pt(SCH_2CO_2)(PPh_3)_2]$ **13**[g]	671	+	—	—	—	—	—	—
$[\{C_6H_4(CH_2NMe_2)\text{-}2\}Au\{SC_6H_4CO_2\}]$ **3a**[e]	1937	4+	4	10	4	6	12	4
$[\{C_6H_3(CH_2NMe_2)\text{-}2\text{-}(OMe)\text{-}5\}Au\{SC_6H_4CO_2\}]$ **3b**[e]	301	3+	2	6	3	5	4	7

[a] The concentration of sample in ng mL^{-1} required to reduce the cell growth of the P388 leukemia cell line (ATCC CCL 46) by 50%. [b] Cytotoxicity to BSC cells; ND denotes no discernible antiviral or cytotoxic effects, +− denotes minor effects located under the disc, + denotes antiviral or cytotoxic zone 1–2 mm excess radius from disc (25% zone), 2+ denotes antiviral or cytotoxic zone 2–4 mm excess radius from the disc (50% zone), 3+ denotes antiviral or cytotoxic zone 4–6 mm excess radius from the disc (75% zone), 4+ denotes antiviral or cytotoxic zone over the whole well (100% zone). [c] Ec = *Escherichia coli*, Bs = *Bacillus subtilis*, Pa = *Pseudomonas aeruginosa*, Ca = *Candida albicans*, Tm = *Trichophyton mentagrophytes*, Cr = *Cladosporium resinae*. [d] Inhibition zone as excess radius (mm) from a 6 mm (diameter) disc containing 2 μg of sample. [e] Data from ref. 3. [f] Not determined. [g] Synthesised according to ref. 2.

$[Pt(SC_6H_4CO_2)(PPh_3)(MeOH)Cl]^-$ (*m*/*z* 677). At 80 V, $[Pt(SC_6H_4CO_2)(PPh_3)Cl]^-$ is the base peak, suggesting that the dinuclear species is undergoing fragmentation across the bridging thiolate–Pt bond, generating $[Pt(SC_6H_4CO_2)(PPh_3)Cl]^-$, and the neutral fragment $[Pt(SC_6H_4CO_2)(PPh_3)(NH_3)]$.



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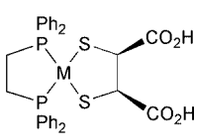

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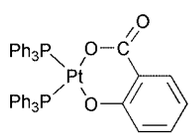

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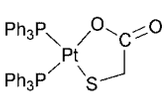

13

Biological activity of thiosalicylate complexes

We have previously reported that the gold(III) thiosalicylate complexes, in particular the methoxy-functionalised complex **3b**, show marked antitumour and antimicrobial activity.[3] The platinum and palladium thiosalicylate complexes **4** have a similar arrangement of two mutually *cis*, high *trans*-influence ligands which are *trans* to two mutually *cis*, low *trans*-influence ligands. The related gold complex **10** has shown appreciable activity against Chinese hamster ovary cells, comparable to that shown by the clinical drug cisplatin, *cis*-$[PtCl_2(NH_3)_2]$.[12] Further impetus for studying the biological activities of these thiosalicylate complexes comes from the observation that platinum(II) complexes containing methylsulfinyl and methylsulfanyl derivatives of thiosalicylate (*e.g.* **8**) have been found to show antitumour activity.[5,13] However, platinum(II) and palladium(II) complexes (**11**) with dithiolate-containing ligands such as dimercaptosuccinate show reduced cytotoxicity,[14] suggesting that the presence of a labile carboxylate ligand might be useful in increasing the activity of this class of complex.

The biological activities of a number of thiosalicylate complexes have been determined, in order to compare: (i) platinum with palladium complexes; (ii) the effect of phosphine *versus* pyridine ligands; (iii) thiosalicylate *versus* salicylate and mercaptoacetate (SCH_2CO_2) ligands (in complexes **12** and **13** respectively); and (iv) the effect of a bidentate chelating ligand (dppe). The phosphatriazaadamantane (pta) complex **2b** was also included in the study because of the water-solubility of pta complexes.[15] Assay data are summarised in Table 6.

Against P388 leukemia cells, the complexes $[Pt(SCH_2CO_2)(PPh_3)_2]$ **13** and $[Pt(SC_6H_4CO_2)(dppe)]$ **2c** exhibit low IC_{50} values (the amount required to inhibit cell growth by 50%) of 671 and 799 ng mL^{-1} respectively, which equates to very high activity. These two complexes were the most active of those tested, but they are still less effective than the gold(III) thiosalicylate complex **3b**, which has an IC_{50} of 301 ng mL^{-1}.[3] Moderate antitumour activity is exhibited by the complexes $[Pt(SC_6H_4CO_2)(PPh_3)(py)]$ **4a**, $[Pt(SC_6H_4CO_2)(PPh_3)_2]$ **2a**, and $[Pd(SC_6H_4CO_2)(PPh_3)_2]$ **2d**, all three of which have an IC_{50} value between 1200 and 2600 ng mL^{-1}. The remaining compounds were not significantly active.

In the antimicrobial assay, seven of the compounds tested showed little activity against the bacteria *Escherichia coli*, *Bacillus subtilis* and *Pseudomonas aeruginosa*, and the fungi *Candida albicans*, *Trichophyton mentagrophytes* and *Cladosporium resinae*. However, the complex $[Pt(SC_6H_4CO_2)(PPh_3)_2]$ **2a** showed extremely high activity against the microbes tested, unusually high values for these types of tests. The complex has even higher activity than the gold(III) complex **3b**, which also displayed high antimicrobial and antifungal activities. The antimicrobial minimum inhibitory concentration (MIC; range between the highest concentration allowing growth and the lowest inhibiting growth) for $[Pt(SC_6H_4CO_2)(PPh_3)_2]$ **2a** against the bacterium *Bacillus subtilis* was measured at 3–6 μg mL^{-1} (3.4–6.9 μmol L^{-1}), this being one of the most sensitive

Gram-positive organisms used in these tests. This range is comparable to the MIC values recorded against the related bacterium, *Escherichia coli*, for **10**, which has itself indicated a potential *in vitro* selectivity for Gram-positive bacteria.[12] In general the compounds show no antiviral activity since their cytotoxicity killed most or all of the BSC-1 cell line used in the test.

Experimental

Materials and methods

General experimental procedures and instrumentation were as described previously.[2] Electrospray mass spectra were recorded in positive-ion mode in MeCN–H_2O (1 : 1 v/v) solution (unless otherwise stated), and ion assignment was aided by comparison of experimental and calculated isotope patterns, the latter obtained using the *Isotope* program.[16] NMR spectra were recorded in $CDCl_3$ solution unless otherwise stated. The following compounds were used as supplied from commercial sources: pyridine (BDH), 4-methylpyridine (BDH), triphenylphosphine (Pressure Chemical Co.), thiosalicylic acid (Sigma), 4-picolinic acid hydrazide (Merck), imidazole (Aldrich). The compounds $[PtCl_2(cod)]$,[17] $[PdCl_2(cod)]$,[18] **2a**–**2d**, **12** and **13** were synthesised by the literature procedures.[2] Assays for biological activity were carried out by Gill Ellis of the Marine Chemistry Group, University of Canterbury. Reactions were carried out in LR grade methanol solvent, without exclusion of air.

Syntheses

$[Pt(SC_6H_4CO_2)(PPh_3)(py)]$ 4a. A mixture of $[PtCl_2(cod)]$ (605 mg, 1.616 mmol), triphenylphosphine (424 mg, 1.616 mmol), thiosalicylic acid **1** (249 mg, 1.616 mmol) and pyridine (10 drops, excess) in methanol (30 mL) was heated under reflux for 20 min giving a bright yellow solution. The volume was reduced to one-third, refrigerated overnight, and the resulting bright yellow microcrystals were filtered off, washed with methanol (5 mL), diethyl ether (20 mL) and dried under vacuum for 2 h to give 641 mg (58%) of **4a**. From a separate preparation, crystals of the monohydrate suitable for an X-ray diffraction study were obtained. A sample for elemental analysis was recrystallised from CH_2Cl_2–diethyl ether. Mp 230–232 °C (decomp.). Found: C, 52.1; H, 3.6; N, 2.1. $C_{30}H_{24}NO_2PPtS$ requires C, 52.3; H, 3.5; N, 2.0%. ^{31}P-$\{^1H\}$ NMR, δ 10.0, [s, ^1J(PtP) 4146]. IR, ν(C=O) 1596(vs), 1575(s, sh) cm^{-1}.

$[Pt(SC_6H_4CO_2)(PPh_3)(Mepy)]$ 4b. Following the method for **4a**, yellow crystals (75 mg, 40%) of **4b** were obtained starting from $[PtCl_2(cod)]$ (101 mg, 0.269 mmol), triphenylphosphine (71 mg, 0.269 mmol), thiosalicylic acid (42 mg, 0.269 mmol) and 4-methylpyridine (10 drops, excess). Mp >230 °C (decomp.). Found: C, 50.5; H, 3.7; N, 1.9. $C_{31}H_{26}NO_2PPtS$ requires C, 53.0; H, 3.7, N, 2.0%. $C_{31}H_{26}NO_2PPtS{\cdot}2H_2O$ requires C, 50.4; H, 4.1; N, 1.9%. NMR: ^{31}P-$\{^1H\}$, δ 9.9 [s, ^1J(PtP) 4160]. IR, ν(C=O) 1618(s, sh), 1591(vs) cm^{-1}.

$[Pt(SC_6H_4CO_2)(PPh_3)(pic)]$ 4c. A mixture of $[PtCl_2(cod)]$ (300 mg, 0.802 mmol), PPh_3 (210 mg, 0.802 mmol), thiosalicylic acid (124 mg, 0.805 mmol) and 4-picolinic acid hydrazide (pic) (600 mg, excess) in methanol (20 mL) was heated under reflux for 20 min giving a clear deep yellow solution. After cooling and standing overnight yellow microcrystals had formed, which were filtered off, washed with methanol–water (1 : 1, 15 mL) and dried to give **4c** (200 mg, 33%). Found: C, 49.2; H, 3.5; N, 5.65. $C_{31}H_{26}N_3O_3PPtS$ requires C, 49.9; H, 3.5; N, 5.6%. Mp 230–234 °C. ^{31}P-$\{^1H\}$ NMR, δ 9.8 [s, ^1J(PtP) 4201].

$[Pt(SC_6H_4CO_2)(PPh_3)(imid)]$ 4d. A mixture of $[PtCl_2(cod)]$ (300 mg, 0.802 mmol), PPh_3 (210 mg, 0.802 mmol), thiosalicylic acid (124 mg, 0.805 mmol) and imidazole (600 mg, excess) in methanol (25 mL) rapidly gave a clear, bright yellow solution. After heating under reflux for 2 h the mixture was cooled to room temperature, and the yellow precipitate filtered off, washed with cold methanol (3 mL), water (5 mL), ethanol (5 mL) and diethyl ether (2 × 5 mL), and dried. Yield 340 mg (63%). Found: C, 49.5; H, 3.4; N, 4.2. $C_{28}H_{22}N_2O_2PPtS$ requires C, 49.7; H, 3.3; N, 4.1%. Mp 236–239 °C. ^{31}P-$\{^1H\}$ NMR, δ 8.4 [s, ^1J(PtP) 4196].

$[Pd(SC_6H_4CO_2)(PPh_3)(py)]$ 4e. $[PdCl_2(cod)]$ (400 mg, 1.40 mmol), triphenylphosphine (366 mg, 1.40 mmol), thiosalicylic acid (215 mg, 1.40 mmol) and pyridine (1 mL, excess) were heated under reflux in methanol (30 mL) for 20 min. Evaporation to *ca.* one-third gave orange crystals, which were filtered off, washed with cold methanol (5 mL), water (10 mL), and diethyl ether (10 mL) and vacuum dried to give 700 mg (84%) of **4e**. Found: C, 60.0; H, 4.05; N, 2.3. $C_{30}H_{24}NO_2PPdS$ requires C, 60.1; H, 4.0; N, 2.3%. Mp 210–216 °C. ^{31}P-$\{^1H\}$ NMR, δ 34.9 (s), plus a small peak at δ 26.7 (s). IR, ν(C=O) 1592 (vs), 1570 (vs) cm^{-1}.

$[Pt_2(SC_6H_4CO_2)_2(PPh_3)_2(NH_3)]{\cdot}1.5MeOH$ 5·1.5MeOH. A mixture of $[PtCl_2(cod)]$ (101 mg, 0.270 mmol), PPh_3 (71 mg, 0.271 mmol), thiosalicylic acid (41.8 mg, 0.271 mmol) and conc. NH_3 solution (10 drops, excess) in methanol (30 mL) was heated at reflux for 20 min to give a pale yellow solution, and the volume reduced to *ca.* one-third. ESMS showed the formation of $[Pt(SC_6H_4CO_2)(PPh_3)_2]$ and some $[Pt(SC_6H_4CO_2)(PPh_3)(NH_3)]$, so the reaction was continued for 24 h with fresh conc. NH_3 (1 mL) and additional MeOH (20 mL). ESMS again showed mainly $[Pt(SC_6H_4CO_2)(PPh_3)_2]$, together with more $[Pt(SC_6H_4CO_2)(PPh_3)(NH_3)]$ and $[Pt_2(SC_6H_4CO_2)_2(PPh_3)_2(NH_3)]$. The volume was reduced to one-third, stored at −18 °C for 2 days, whereupon some greenish-grey precipitate was deposited. The solution was filtered and the filtrate allowed to stand for 5 weeks. A small quantity of yellow plates (28 mg) formed, and one was characterised as **5** by a single-crystal X-ray diffraction study. The crystals appear to lose solvent when air dried. Found: C, 46.7; H, 3.5; N, 1.3. $C_{50}H_{41}NO_4P_2Pt_2S_2{\cdot}1.5MeOH$ requires C, 48.1; H, 3.6; N, 1.1%. Mp decomp. >250 °C with gas evolution.

Crystallography

Crystal data, collection and refinement details are summarised in Table 7. Non-routine features are as follows.

Structure determination of $[Pt(SC_6H_4CO_2)(PPh_3)(py)]{\cdot}H_2O$ 4a·H_2O. Data were collected to 56° but the higher angle data were very weak because of the small crystal size, so only the data below 48° were used in the refinement. Refinement was complicated by disorder of the pyridine ring, which was modelled as two half-occupied sites with isotropic thermal parameters. Both disordered components were co-planar, one displaced upwards and one downwards with respect to the platinum coordination plane. There was also concomitant disorder of the carboxylate part of the thiosalicylate ligand, but this was less pronounced so was absorbed into the anisotropy of the atoms in this region. A penultimate difference map revealed a double peak assigned as a disordered water of crystallisation H-bonded to the free O(2) of the thiosalicylate ligand. Hydrogen atoms were included in their calculated positions only for the phenyl and thiosalicylate rings.

Structure determination of $[Pt(SC_6H_4CO_2)(PPh_3)(XyNC)]{\cdot}Me_2CO$ 7·Me_2CO. The complex was prepared as a mixture of *cis*/*trans* isomers (**7** is the major isomer) by the literature

Table 7 Crystal and refinement data for $[Pt(SC_6H_4CO_2)(PPh_3)(py)]\cdot H_2O$ **4a**·H_2O, $[Pt(SC_6H_4CO_2)(PPh_3)(XyNC)]\cdot Me_2CO$ **7**·Me_2CO, and $[Pt_2(SC_6H_4CO_2)_2(PPh_3)_2(NH_3)]\cdot 1.5MeOH$ **5**·1.5MeOH

	4a·H_2O	**7**·Me_2CO	**5**·1.5H_2O
Empirical formula	$C_{30}H_{24}NO_2PPtS\cdot H_2O$	$C_{34}H_{28}NO_2PPtS\cdot C_2H_6CO$	$C_{50}H_{41}NO_4P_2Pt_2S_2\cdot 1.5CH_3OH$
Formula weight	706.64	798.77	1284.14
Crystal system	Monoclinic	Triclinic	Monoclinic
Space group	*C*2/*c*	$P\bar{1}$	*C*2/*c*
a/Å	18.7231(10)	10.5158(10)	31.5133(19)
b/Å	17.3019(10)	15.1613(2)	11.2727(6)
c/Å	17.6543(10)	21.4698(2)	26.8046(14)
α/°	90	73.346(10)	90
β/°	103.360(10)	85.576(10)	90.062(2)
γ/°	90	87.630(10)	90
Volume/Å^3	5564.25(5)	3268.98(6)	9522.1(9)
T/K	203(2)	203(2)	203(2)
Z	8	4	8
Absorption coefficient/mm^{-1}	5.208	4.442	6.075
Reflections collected	27133	27558	25267
Independent reflections	4377 [$R_{(int)}$ = 0.045]	12946 [$R_{(int)}$ = 0.0228]	9574 [$R_{(int)}$ = 0.0485]
Final *R* indices [$I > 2\sigma(I)$]	R_1 = 0.0703	R_1 = 0.0244	R_1 = 0.0472
R indices (all data)	R_1 = 0.0999, wR_2 = 0.1410	R_1 = 0.0295, wR_2 = 0.0583	R_1 = 0.0561, wR_2 = 0.0965

procedure,[2] starting from $[Pt(SC_6H_4CO_2)(PPh_3)_2]$ and XyNC. Recrystallisation from a mixture of chloroform, acetone and diethyl ether by slow evaporation at 4 °C gave very pale yellow tablets of the major isomer **7**.

Structure determination of $[Pt_2(SC_6H_4CO_2)_2(PPh_3)_2(NH_3)]\cdot 1.5MeOH$ 5·1.5MeOH. Penultimate difference maps showed two solvent (methanol) regions, one ordered, and one disordered and lying on a two-fold axis, giving 1.5 MeOH overall. All non-hydrogen atoms were assigned anisotropic thermal parameters except for those of the disordered methanol. The H atoms associated with the solvent molecules were not included.

CCDC reference number 186/2072.

See http://www.rsc.org/suppdata/dt/b0/b003619f/ for crystallographic files in .cif format.

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