organic compounds

The proton-transfer compounds of strychnine with achiral salicylic acids: strychninium 3,5-dinitrosalicylate and the strychninium 5-nitrosalicylate bis(5-nitrosalicylic acid) adduct

Graham Smith,[a]* Urs D. Wermuth[a] and Jonathan M. White[b]

[a]School of Physical and Chemical Sciences, Queensland University of Technology, GPO Box 2434, Brisbane 4001, Australia, and [b]School of Chemistry, University of Melbourne, Parkville, Victoria 3052, Australia
Correspondence e-mail: g.smith@qut.edu.au

In the crystal structures of the proton-transfer compounds of strychnine with 3,5-dinitrosalicylic acid, namely strychninium 3,5-dinitrosalicylate, $C_{21}H_{23}N_2O_2{}^+ \cdot C_7H_3N_2O_7{}^-$, (I), and 5-nitrosalicylic acid, namely strychninium–5-nitrosalicylate–5-nitrosalicylic acid (1/1/2), $C_{21}H_{23}N_2O_2{}^+ \cdot C_7H_4NO_5{}^- \cdot 2C_7H_5NO_5$, (II), protonation of one of the N atoms of the strychnine molecule occurs and this group is subsequently involved in intermolecular hydrogen-bonding interactions. In (I), this is four-centred, the primary being with an adjacent strychninium carbonyl O-atom acceptor in a side-to-side interaction giving linear chains. Other interactions are with the phenolate and nitro O-atom acceptors of the anionic species, resulting in a one-dimensional polymer structure. In (II), the N^+—H interaction is three-centred, the hydrogen bonding involving carboxyl O-atom acceptors of the anion and both acid adduct species, giving unique discrete hetero-tetramer units. The structure of (II) also features π-bonding interactions between the two acid adduct molecules.

Comment

Strychnine and brucine have been variously employed on a hit-or-miss basis as resolving agents for a range of chiral organic compounds, and the crystal structures of a large number of complexes with strychnine and brucine, together with their absolute configurations, have been determined. The complexes include those with acidic species, in which atom N19 of the strychnine or brucine molecule (pK_{a2} = 11.7) is protonated, e.g. the N-benzoyl-, N-phthaloyl- and N-acetyl-protected amino acids (Gould & Walkinshaw, 1984; Gould, Taylor & Walkinshaw, 1984; Gould et al., 1985; Białońska & Ciunik, 2004a; Quinkert et al., 1986; Kuwata et al., 1993), and other chiral acid types (Gould et al., 1987, 2002; Boiadjiev et

al., 1992; Wright et al., 1994; Bao et al., 1996; Costente et al., 1996; Dijksma, Gould, Parsons, Taylor & Walkinshaw, 1998; Andersson et al., 1999; Allenmark & Skogsberg, 2000; Białońska et al., 2005). Other structures with neutral chiral guest species are known, e.g. with alcohols, lactones, cyanohydrins and ketones (Toda et al., 1981, 1985; Tanaka et al., 2001; Chandramohan & Ravikumar, 1999; Pinkerton et al., 1993; Yamagishi et al., 1992).
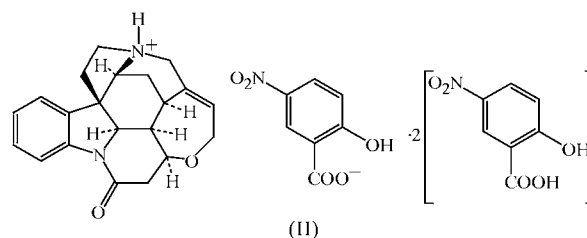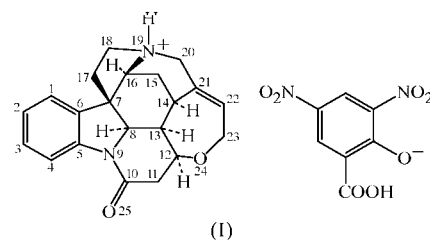
Although strychnine and brucine are both physicochemically and structurally similar and configurationally identical, brucine has proved to be the better of the two for optical resolution. This appears to be because of the methoxy groups in the 2- and 3-positions of the aromatic ring influencing the solid-state packing of the brucine molecules, which commonly form undulating parallel chain structures (Gould & Walkinshaw, 1984; Dijksma et al., 1998; Białońska et al., 2005). These recognize compatible molecular guest species which occupy the interstitial cavities between the chains and associate with the host through hydrogen bonding. Water or other molecules of solvation may also act, if needed, in a space-filling and/or in a proton-donor or -acceptor capacity. This is apparent in the isomorphous crystals of brucine–ethanol–water (1/1/2) (Glover et al., 1985) and brucine–propan-2-ol–water (1/1/2) (Białońska & Ciunik, 2004b), and in brucine–acetone (1/1) structures (Białońska & Ciunik, 2004b). Strychnine is less regular as a host structure for organic molecule recognition, often giving isolated molecular complexes or forming double-layer polymeric structures (Gould & Walkinshaw, 1984; Dijksma, Gould, Parsons, Taylor & Walkinshaw, 1998).

More recently, the structures of a number of neutral and proton-transfer compounds of strychnine and brucine with achiral organic molecules have been determined, e.g. with 4-nitrophenol (Guo et al. 2001), fumaric and maleic acids (Dijksma, Gould, Parsons & Walkinshaw, 1998), 4-hydroxybenzoic acid (Sada et al., 1998), 3-nitrobenzoic acid (Oshikawa et al., 2002) and 8-aminonaphthalene-2-sulfonic acid (Smith, Wermuth, Healy & Young, 2005). Because it was observed by Oshikawa et al. (2002) that brucine has a recognitive affinity for meta-substituted benzoic acids, we therefore considered that the analogous acids 3,5-dinitrosalicylic acid (DNSA),
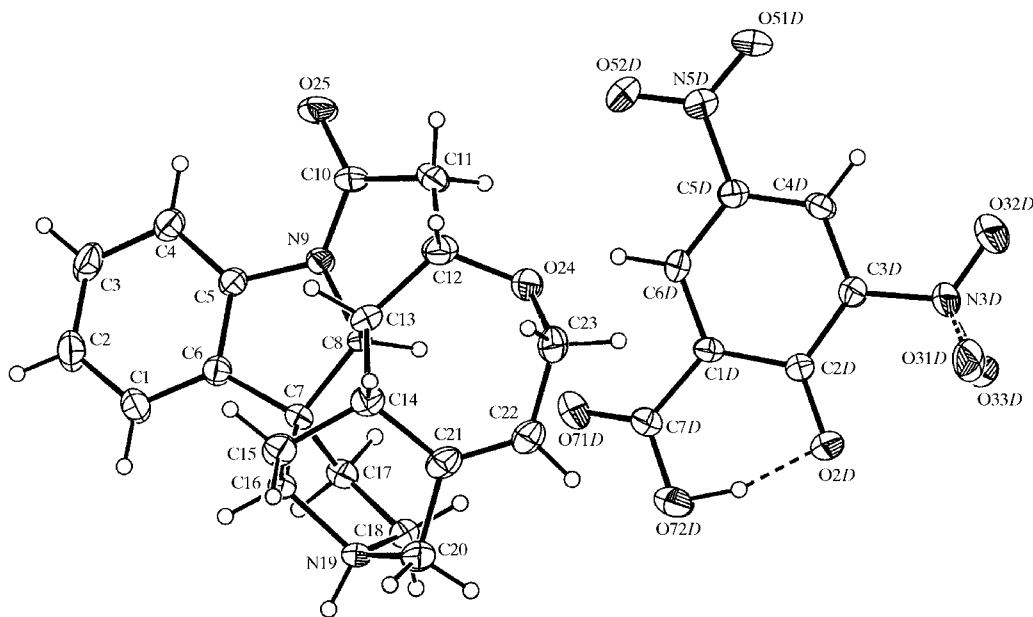
Figure 1
The molecular configuration and atom-numbering scheme for the strychninium cation and the DNSA anion species in compound (I). Displacement ellipsoids are drawn at the 30% probability level and H atoms are shown as small spheres of arbitrary radii. Atoms O31D and O33D are disordered sites (see *Comment*).

5-nitrosalicylic acid (5-NSA), 5-sulfosalicylic acid (5-SSA) and 3-nitrophthalic acid (NPA) were likely candidates for similar recognition by brucine and possibly strychnine. This has proved to be the case with brucine, where good crystalline products were obtained within one week for DNSA, two weeks for 5-NSA and 5-SSA, and several weeks with NPA. The crystal structures of all four compounds have now been determined (Smith, Wermuth & Healy, 2005; Smith, Wermuth, Young & Healy, 2005). However, with strychnine, no complex was obtained with 5-SSA or NPA, although good crystals of the compounds with DNSA and 5-NSA were formed, albeit more slowly than with brucine. The crystal structures of these two compounds, strychninium 3,5-dinitrosalicylate, (I), and the adduct strychninium–5-nitrosalicylate–5-nitrosalicylic acid (1/1/2), (II), respectively, are reported here.

Compounds (I) and (II) are both anhydrous, which is consistent with the structures of the proton-transfer compounds of both DNSA and 5-NSA with Lewis bases, where water or other molecules of solvation are seldom incorporated (Smith *et al.*, 2002, 2003; Smith, Hartono *et al.*, 2005), although the brucine complex with DNSA is a mono-hydrate (Smith, Wermuth & Healy, 2005). The major difference between (I) and (II) is the presence in (II) of two additional adduct molecules of 5-NSA acid, adduct formation being unusual among 5-NSA compounds, as well as among examples of brucine or strychnine complexes.

In the structures of both (I) and (II) (Figs. 1 and 2), the expected proton transfer to N19 of the strychnine molecule occurs and this group is subsequently involved in inter-molecular $N^+{-}H\cdots O$ hydrogen-bonding interactions with two O-atom acceptors of the anion species, and, in the case of (I), a strychnine carbonyl O atom (Tables 1 and 2).

In each structure, the absolute configuration of the parent strychnine molecule (Peerdeman, 1956) is invoked. This includes the 'apparent' change in configuration at C7 (R to S), which is a consequence of the change in the heirarchy of the protonated N19 group in the Cahn–Ingold–Prelog system and the introduction of a new chiral centre at N19 (S) (Smith, Wermuth, Healy & Young, 2005). This gives the overall absolute stereochemistry for the strychninium cations in (I) and (II) (as with all proton-transfer compounds of both brucine and strychnine) as C7(S), C8(S), C12(S), C13(R), C14(R), C16(S) and N19(S).

In (I), the linear strychninium framework is formed through side-to-side hydrogen-bonding interactions involving the protonated N19 group and an adjacent strychnine carbonyl O atom [N19–H19$\cdots$O25^i = 3.148 (4) Å; see Table 1 for symmetry code], extending along the c-axis direction (Fig. 3). Atom N19 is then involved in a proximal association with both a phenolic-O and a disordered nitro-O acceptor of a glide-related DNSA anion [N19$\cdots$O2D^{ii} = 2.857 (5) and N19$\cdots$O33D^{ii} = 3.00 (3) Å; see Table 1 for symmetry code]. This generates a linear polymer structure in which, surprisingly, there are no intermolecular associations involving the O-atom acceptors of the DNSA carboxyl group.

In (II), an unusual discrete hetero-tetramer is formed, comprising the strychninium cation, the 5-NSA anion (molecule B) and the two 5-NSA acid adduct molecules (A and C) (Fig. 4). The three-centre association with N19$^+{-}$H involves carboxyl-O acceptors of the anion [N19$\cdots$O72B^i = 3.223 (8) Å; see Table 2 for symmetry code] and an adduct molecule A [N19$\cdots$O72A^{ii} = 2.958 (5) Å. Completing a cyclic $R_2^2(6)$ association is the carboxyl H atom of the adduct molecule A [O71$A\cdots$O72B^{ii} = 2.553 (6) Å]. The second adduct
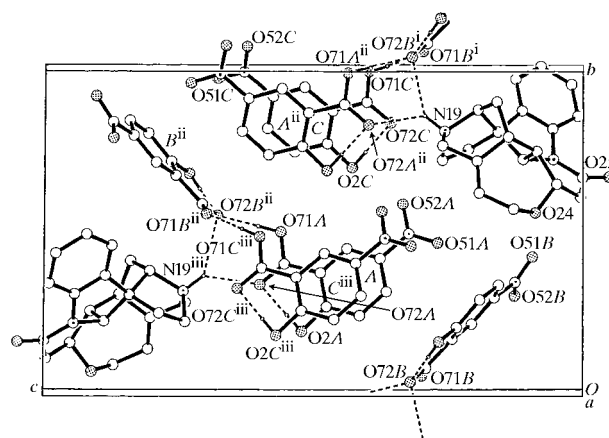
organic compounds
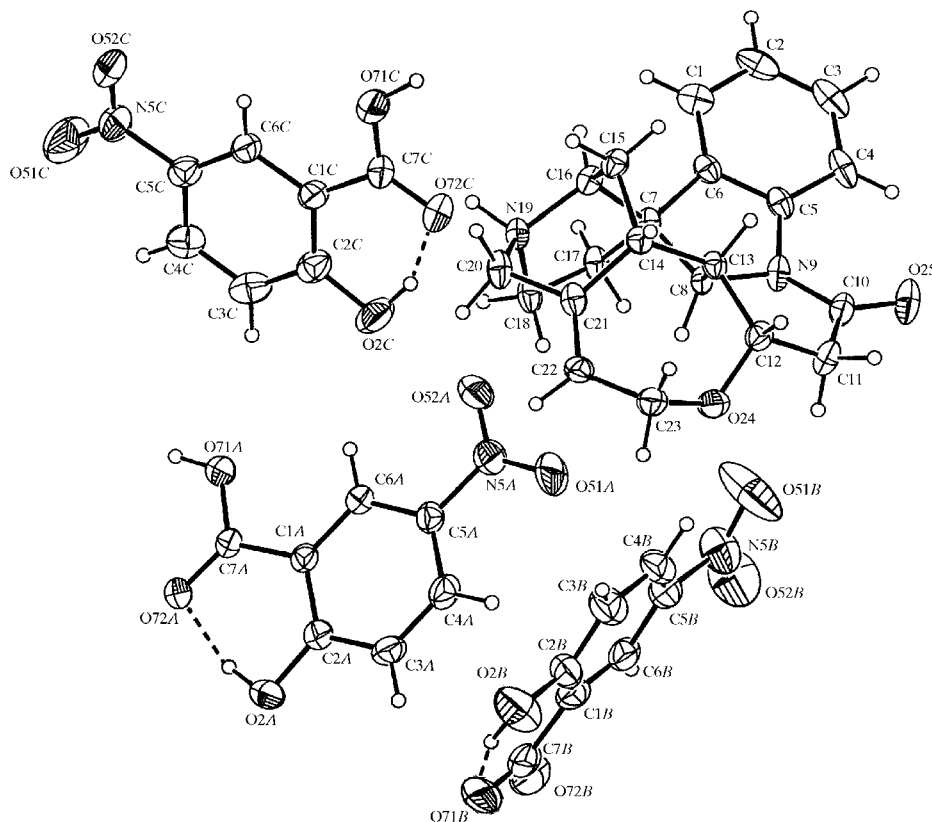
Figure 2
The molecular configuration and atom-numbering scheme for the strychninium cation, the 5-NSA anion and the two 5-NSA acid adduct species in compound (II). Displacement ellipsoids are drawn at the 30% probability level and H atoms are shown as small spheres of arbitrary radii.
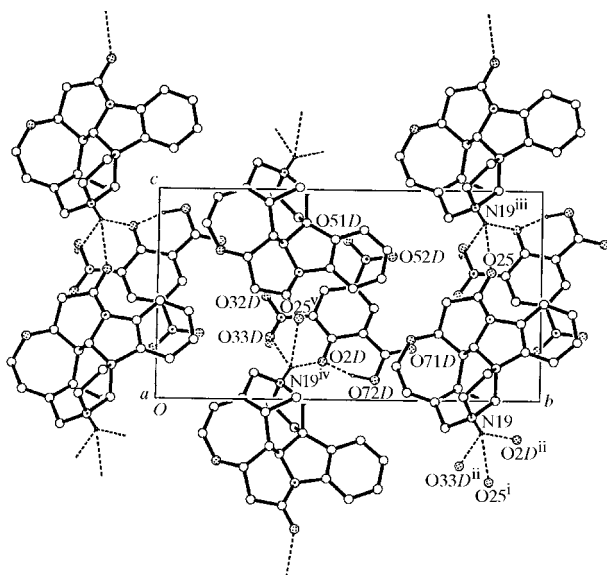
Figure 3
The packing of (I) in the unit cell, viewed down the *a* axis. Non-interacting H atoms have been omitted. Hydrogen-bonding associations are shown as broken lines. [Symmetry codes: (iii) $x, y, 1 + z$; (iv) $-x, y - \frac{1}{2}, -z$; (v) $-x, y - \frac{1}{2}, 1 - z$; for others, see Table 1.]

Figure 4
The packing of (II) in the unit cell, viewed down the *c* axis. The discrete hydrogen-bonded tetrameric units are shown (dashed lines). Also illustrated are the π-bonding associations between the two 5-NSA adduct molecules (*A* and *C*). [Symmetry codes: (iii) $1 - x, y - \frac{1}{2}, 1 - z$; for others, see Table 2.]

separations: $CgA \cdots CgC = 3.72\,(1)$ (intra) and $4.09\,(1)$ Å (inter); CgA and CgC denote the centroids of the rings in molecules *A* and *C*, respectively]. Both adduct formation and π-stacking effects are previously unknown among structures of 5-NSA compounds (Smith, Hartono *et al.*, 2005). The tetramer units are unassociated, except for an unusual side-on

molecule is linearly hydrogen bonded to the anion molecule through the carboxyl groups [2.709 (8) Å], such that both adduct molecules form π-associated stacks [ring centroid

interaction between the intramolecularly hydrogen-bonded phenol group of an adduct molecule C and a nitro O atom of an adjacent adduct molecule A [O2C···O52A = 2.854 (6) Å] (Figs. 2 and 4).

Within the DNSA anion in (I), the structural features vary slightly from those of the majority of proton-transfer compounds (Smith *et al.*, 2003), particularly with regard to the conformation of the nitro-substituent groups. The proximal nitro group at C3 is more commonly involved in hydrogen bonding than the C5 nitro group and therefore usually shows a greater rotation out of the plane of the ring than the C5 group. In (I), this is also the case [C2D—C3D—N3D—O33D = 167.4 (5)° and C4D—C5D—N5D—O52D = 179.5 (4)°]. However, the previously mentioned intermolecularly unassociated carboxyl group is non-coplanar [C2D—C1D—C7D—O71D = −166.4 (4)°], although it is involved in the intramolecular hydrogen bond. This hydrogen bond [O2D···O72D = 2.492 (5) Å] has the H atom located on the carboxyl O atom, rather than on the phenol group as is found in *ca* 70% of the proton-transfer compounds of DNSA (Smith *et al.*, 2002, 2003).

With the 5-NSA species in (II), despite the presence of adduct acid molecules and the associated π-stacking effects, structural features vary little from those previously reported (Smith, Hartono *et al.*, 2005), which includes near-coplanarity between the parent ring and both the carboxyl- and nitro-substituent groups, the invariable location of the intramolecular H atom on the phenol O atom, and a contraction of this intramolecular O···O distance with deprotonation [2.509 (10) Å in molecule B, compared with 2.595 (5) Å in molecule A and 2.605 (6) Å in molecule C].

Experimental

The title compounds were synthesized by heating 1 mmol quantities of strychnine (strychnidin-10-one) and either 3,5-dinitrosalicylic acid (DNSA) or 5-nitrosalicylic acid (5-NSA) in 50% ethanol–water (50 ml) for 10 min under reflux. After concentration to *ca* 30 ml, partial room-temperature evaporation of the hot-filtered solutions gave yellow prisms of (I) (m.p. 468–470 K) and minor colourless prisms of (II) (m.p. 487–489 K).

Compound (I)

Crystal data

$C_{21}H_{23}N_2O_2{}^+ \cdot C_7H_3N_2O_7{}^-$	$D_x = 1.536$ Mg m^{-3}
$M_r = 562.53$	Mo $K\alpha$ radiation
Monoclinic, $P2_1$	Cell parameters from 2715
$a = 7.5036 (15)$ Å	reflections
$b = 17.219 (3)$ Å	$\theta = 2.4$–27.3°
$c = 9.4799 (19)$ Å	$\mu = 0.12$ mm^{-1}
$\beta = 96.905 (3)$°	$T = 295 (2)$ K
$V = 1216.0 (4)$ Å^3	Block, yellow
$Z = 2$	$0.40 \times 0.30 \times 0.20$ mm

Data collection

Bruker SMART CCD area-detector diffractometer	$R_{int} = 0.071$
φ and ω scans	$\theta_{max} = 25.0$°
5865 measured reflections	$h = -8 \rightarrow 8$
2222 independent reflections	$k = -20 \rightarrow 18$
1909 reflections with $F^2 > 2\sigma(F^2)$	$l = -10 \rightarrow 11$

Refinement

Refinement on F^2	$w = 1/[\sigma^2(F_o{}^2) + (0.0734P)^2$
$R[F^2 > 2\sigma(F^2)] = 0.058$	$+ 0.1261P]$
$wR(F^2) = 0.142$	where $P = (F_o{}^2 + 2F_c{}^2)/3$
$S = 1.17$	$(\Delta/\sigma)_{max} = 0.021$
2222 reflections	$\Delta\rho_{max} = 0.22$ e Å^{-3}
384 parameters	$\Delta\rho_{min} = -0.25$ e Å^{-3}
H atoms treated by a mixture of independent and constrained refinement	

Table 1
Hydrogen-bond geometry (Å, °) for (I).

D—H···A	D—H	H···A	D···A	D—H···A
O72D—H72D···O2D	1.02	1.50	2.492 (5)	165
N19—H19···O25^{i}	0.91 (5)	2.59 (5)	3.148 (4)	120 (4)
N19—H19···O2D^{ii}	0.91 (5)	2.11 (5)	2.857 (5)	139 (4)
N19—H19···O33D^{ii}	0.91 (5)	2.41 (6)	3.00 (3)	123 (4)

Symmetry codes: (i) $x, y, z - 1$; (ii) $1 - x, y + \frac{1}{2}, -z$.

Compound (II)

Crystal data

$C_{21}H_{23}N_2O_2{}^+ \cdot C_7H_4NO_5{}^- \cdot$ $2C_7H_5NO_5$	Cu $K\alpha$ radiation
	Cell parameters from 25
$M_r = 883.77$	reflections
Monoclinic, $P2_1$	$\theta = 20$–30°
$a = 7.5762 (9)$ Å	$\mu = 1.01$ mm^{-1}
$b = 12.3729 (9)$ Å	$T = 295 (2)$ K
$c = 20.891 (4)$ Å	Prismatic, colourless
$\beta = 97.96 (1)$°	$0.30 \times 0.20 \times 0.20$ mm
$V = 1939.5 (5)$ Å^3	
$Z = 2$	
$D_x = 1.513$ Mg m^{-3}	

Data collection

Enraf–Nonius CAD-4F diffractometer	$\theta_{max} = 69.9$°
$\omega/2\theta$ scans	$h = -9 \rightarrow 9$
3960 measured reflections	$k = 0 \rightarrow 15$
3856 independent reflections	$l = 0 \rightarrow 25$
3427 reflections with $F^2 > 2\sigma(F^2)$	3 standard reflections
$R_{int} = 0.045$	frequency: 160 min
	intensity decay: none

Refinement

Refinement on F^2	$w = 1/[\sigma^2(F_o{}^2) + (0.1204P)^2$
$R[F^2 > 2\sigma(F^2)] = 0.056$	$+ 0.567P]$
$wR(F^2) = 0.168$	where $P = (F_o{}^2 + 2F_c{}^2)/3$
$S = 1.02$	$(\Delta/\sigma)_{max} = 0.002$
3856 reflections	$\Delta\rho_{max} = 0.57$ e Å^{-3}
585 parameters	$\Delta\rho_{min} = -0.35$ e Å^{-3}
H atoms treated by a mixture of independent and constrained refinement	

Table 2
Hydrogen-bond geometry (Å, °) for (II).

D—H···A	D—H	H···A	D···A	D—H···A
N19—H19···O72B^{i}	0.99 (13)	2.52 (7)	3.233 (8)	128 (2)
N19—H19···O72A^{ii}	0.99 (13)	2.19 (13)	2.958 (5)	133 (2)
O71A—H71A···O72B^{ii}	0.91	1.65	2.553 (6)	179
O71C—H71C···O71B^{i}	0.90	1.81	2.709 (5)	179
O2A—H2A···O72A	0.91	1.69	2.595 (5)	180
O2B—H2B···O72B	0.82	1.70	2.509 (10)	168
O2C—H2C···O72C	0.90	1.71	2.605 (6)	179

Symmetry codes: (i) $x, y + 1, z$; (ii) $1 - x, y + \frac{1}{2}, 1 - z$.

organic compounds

H atoms potentially involved in hydrogen-bonding interactions were located by difference methods but, with the exception of the strychninium atom H19 (on N19), their positional and isotropic displacement parameters were not refined. Other H atoms were included in the refinement in calculated positions (aromatic C—H = 0.93 Å and aliphatic C—H = 0.97 Å) and treated using a riding model, with $U_{iso}(H) = 1.2U_{eq}(C)$. The atom-numbering scheme for the strychninium species in (I) and (II) (Figs. 1 and 2, respectively) follows the original Robinson convention (Holmes, 1952). Friedel pairs were averaged and the absolute configuration determined for the parent strychnine (Peerdeman, 1956) was invoked, giving the overall Cahn–Ingold–Prelog absolute stereochemistry (Eliel, 1962) as C7(S), C8(S), C12(S), C13(R), C14(R), C16(S) and N19(S). One of the nitro O atoms in (I) was found to be disordered and was subsequently refined over two sites [O31D, with a site-occupancy factor of 0.44 (5), and O33D, with a site-occupancy factor of 0.56 (5)].

Data collection: *SMART* (Bruker, 2000) for (I); *CAD-4 Software* (Enraf–Nonius, 1989) for (II). Cell refinement: *SMART* for (I); *CAD-4 Software* for (II). Data reduction: *SAINT* (Bruker, 1999) for (I); *XCAD4* (Harms & Wocadlo, 1995) for (II). Structure solution: *SHELXTL* (Bruker, 1997) for (I); *SHELXS97* (Sheldrick, 1997) in *WinGX* (Farrugia, 1999) for (II). Structure refinement: *SHELXTL* for (I); *SHELXL97* (Sheldrick, 1997) in *WinGX* for (II). For both compounds, molecular graphics: *PLATON* (Spek, 2003); publication software: *PLATON*.

Supplementary data for this paper are available from the IUCr electronic archives (Reference: TA1499). Services for accessing these data are described at the back of the journal.

References

Allenmark, S. & Skogsberg, U. (2000). *Enantiomer*, **5**, 451–455.
Andersson, M., Sundell, S. & Allenmark, S. (1999). *Enantiomer*, **4**, 411–417.
Bao, J., Wulff, W. D., Dominy, J. B., Fumo, M. J., Grant, E. B., Rob, A. C., Whitcomb, M. C., Yeung, S.-M., Ostrander, R. L. & Rheingold, A. L. (1996). *J. Am. Chem. Soc.* **118**, 3392–3405.
Białońska, A. & Ciunik, Z. (2004a). *CrystEngComm*, **6**, 276–279.
Białońska, A. & Ciunik, Z. (2004b). *Acta Cryst.* C**60**, o853–o855.
Białońska, A., Ciunik, Z., Popek, T. & Lis, T. (2005). *Acta Cryst.* C**61**, o88–o91.
Boiadjiev, S. E., Person, R. V., Puzicha, G., Knobler, C., Maverick, E., Trueblood, K. N. & Lightner, D. A. (1992). *J. Am. Chem. Soc.* **114**, 10123–10133.
Bruker (1997). *SHELXTL*. Version 5.10. Bruker AXS Inc., Madison, Wisconsin, USA.
Bruker (1999). *SAINT*. Version 6.02. Bruker AXS Inc., Madison, Wisconsin, USA.
Bruker (2000). *SMART*. Version 5.55. Bruker AXS Inc., Madison, Wisconsin, USA.
Chandramohan, K. & Ravikumar, K. (1999). *J. Chem. Crystallogr.* **29**, 121–125.
Costente, J., Ehlinger, N., Perrin, M. & Collett, A. (1996). *Enantiomer*, **1**, 377–386.
Dijksma, F. J. J., Gould, R. O., Parsons, S., Taylor, P. & Walkinshaw, M. D. (1998). *J. Chem. Soc. Chem. Commun.* pp. 745–747.
Dijksma, F. J. J., Gould, R. O., Parsons, S. & Walkinshaw, M. D. (1998). *Acta Cryst.* C**54**, 1948–1951.
Eliel, E. L. (1962). *Stereochemistry of Carbon Compounds*, pp. 92–94. New York: McGraw–Hill.
Enraf–Nonius (1989). *CAD-4 Software*. Version 5.0. Enraf–Nonius, Delft, The Netherlands.
Farrugia, L. J. (1999). *J. Appl. Cryst.* **32**, 837–838.
Glover, S. S. B., Gould, R. O. & Walkinshaw, M. D. (1985). *Acta Cryst.* C**41**, 990–994.
Gould, R. O., Kelly, R. & Walkinshaw, M. D. (1985). *J. Chem. Soc. Perkin Trans. 2*, pp. 847–852.
Gould, R. O., Taylor, P. & Walkinshaw, M. D. (1984). *Acta Cryst.* A**43**, C-65.
Gould, R. O., Taylor, P., Walkinshaw, M. D., Wimmer, N. & Bruins Slot, H. J. (1987). *Acta Cryst.* C**43**, 2405–2410.
Gould, R. O. & Walkinshaw, M. D. (1984). *J. Am. Chem. Soc.* **106**, 7840–7842.
Gould, R. O., Walkinshaw, M. D., Wimmer, N. & Kosma, P. (2002). *Acta Cryst.* A**58**, C-126.
Guo, W.-S., Guo, F., Deng, M., Ge, C.-H., Liu, Q.-T., Hua, X.-Q., Bai, J.-L., Tian, Z.-Y., Wang, S.-C. & Zheng, Q.-T. (2001). *Huaxue Xuebao*, **59**, 284–290. (In Chinese.)
Harms, K. & Wocadlo, S. (1995). *XCAD4*. University of Marburg, Germany.
Holmes, H. L. (1952). *The Alkaloids*, Vol. II, edited by R. H. F. Manske & H. L. Holmes, p. 514. New York: Academic Publishers Inc.
Kuwata, S., Tanaka, J., Onda, N., Yamada, T., Miyazawa, T., Sigiura, M., In, Y., Doi, M., Inoue, M. & Ishida, T. (1993). *Bull. Chem. Soc. Jpn*, **66**, 1501–1510.
Oshikawa, T., Pochamroen, S., Takai, N., Ide, N., Takemoto, T. & Yamashita, M. (2002). *Heterocycl. Commun.* **8**, 271–274.
Peerdeman, A. F. (1956). *Acta Cryst.* **9**, 824.
Pinkerton, A. A., Carrupt, P.-A., Claret, F. & Vogel, P. (1993). *Acta Cryst.* C**49**, 1632–1636.
Quinkert, G., Schmalz, H.-G., Dzierzynski, E. M., Durner, G. & Batz, J. W. (1986). *Angew. Chem. Int. Ed. Engl.* **25**, 992–993.
Sada, K., Yoshikawa, K. & Miyata, M. (1998). *J. Chem. Soc. Chem. Commun.* pp. 1763–1764.
Sheldrick, G. M. (1997). *SHELXL97* and *SHELXS97*. University of Göttingen, Germany.
Smith, G., Hartono, A. W., Wermuth, U. D., Healy, P. C., White, J. M. & Rae, A. D. (2005). *Aust. J. Chem.* **58**, 47–52.
Smith, G., Wermuth, U. D., Bott, R. C., Healy, P. C. & White, J. M. (2002). *Aust. J. Chem.* **55**, 349–356.
Smith, G., Wermuth, U. D. & Healy, P. C. (2005). *Aust. J. Chem.* In preparation.
Smith, G., Wermuth, U. D., Healy, P. C. & White, J. M. (2003). *Aust. J. Chem.* **56**, 707–713.
Smith, G., Wermuth, U. D., Healy, P. C. & Young, D. J. (2005). *Org. Biomol. Chem.* Submitted.
Smith, G., Wermuth, U. D., Young, D. J. & Healy, P. C. (2005). *Acta Cryst.* E**61**, o2008–o2011.
Spek, A. L. (2003). *J. Appl. Cryst.* **36**, 7–13.
Tanaka, K., Kato, M. & Toda, F. (2001). *Heterocycles*, **54**, 405–410.
Toda, F., Tanaka, K. & Ueda, H. (1981). *Tetrahedron Lett.* **22**, 4669–4672.
Toda, F., Tanaka, K., Ueda, H. & Oshima, T. (1985). *Isr. J. Chem.* **25**, 338–345.
Wright, J. L., Caprathe, B. W., Downing, D. M., Glase, S. A., Heffner, T. G., Jaen, J. C., Johnson, S. J., Kesten, S. R., MacKenzie, R. G., Meltzer, L. T., Pugsley, T. A., Smith, S. J., Wise, L. D. & Wustrow, D. J. (1994). *J. Med. Chem.* **37**, 3523–3533.
Yamagishi, M., Yamada, Y., Ozaki, K., Da-te, T., Okamura, K., Suzuki, M. & Matsumoto, K. (1992). *J. Org. Chem.* **57**, 1568–1571.