

## Strychninium *N*-phthaloyl- $\beta$ -alaninate *N*-phthaloyl- $\beta$ -alanine and brucinium *N*-phthaloyl- $\beta$ -alaninate 5.67-hydrate

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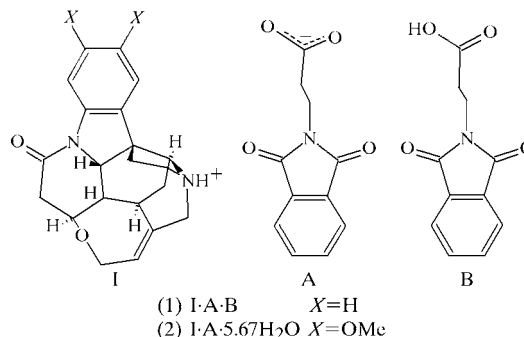
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Comparison of the structures of strychninium *N*-phthaloyl- $\beta$ -alaninate *N*-phthaloyl- $\beta$ -alanine,  $C_{21}H_{23}N_2O_2^+ \cdot C_{11}H_8NO_4^- \cdot C_{11}H_9NO_4$ , and brucinium *N*-phthaloyl- $\beta$ -alaninate 5.67-hydrate,  $C_{23}H_{27}N_2O_4^+ \cdot C_{11}H_8NO_4^- \cdot 5.67H_2O$ , reveals that, unlike strychninium cations, brucinium cations display a tendency to produce stacking interactions with cocrystallizing guests.

### Comment

Strychnine and its dimethoxy derivative, brucine, are well known as resolving agents of racemic acids by fractional crystallization of diastereomeric salts (Jacques *et al.*, 1991; Eliel & Wilen, 1994). Recently, we demonstrated the matching of donor/acceptor properties of both resolved compounds and the surface of self-assembled resolving agents during racemic resolution of *N*-benzoyl- and *N*-phthaloyl- $\alpha$ -alanine by strychnine and brucine (Białońska & Ciunik, 2004). In addition,

various D- or L-enantiomers of the  $\alpha$ -alanine derivative were recognized by the surfaces of self-assembled strychnine and brucine. We describe here the molecular recognition of *N*-phthaloyl- $\beta$ -alanine by both strychnine and brucine in the title compounds, (1) and (2) (Fig. 1).



In (1), the *N*-phthaloyl- $\beta$ -alanine molecules and *N*-phthaloyl- $\beta$ -alaninate anions are linked by O—H...O and C—H...O hydrogen bonds and  $\pi$ — $\pi$  interactions, forming three-dimensional networks with large channels extending along the [100] direction (Fig. 2). The channels are occupied by columns of strychninium cations linked by C—H...O and C—H... $\pi$  hydrogen bonds. A similar strychnine self-assembly was observed in (–)-strychninium (+)-neopentyl phthalate chloroform solvate (Yuan *et al.*, 1994). The strychninium cations and *N*-phthaloyl- $\beta$ -alaninate anions are linked by N—H<sup>+</sup>...O<sup>−</sup> hydrogen bonds, formed between the protonated tertiary amine atom (N2) of the cation and atom O3 of the carboxylate group of the anion (Table 1). The structure is additionally stabilized by a number of weak C—H...O hydrogen bonds.

In (2), the protonated tertiary amine atom (N2) of the brucinium cation is a hydrogen-bond donor, and atom O5 or atoms O5A/O6A of the disordered carboxylate group of the *N*-phthaloyl- $\beta$ -alaninate anion are the acceptors (Table 2). The arene ring of the brucinium cation and the phthaloyl

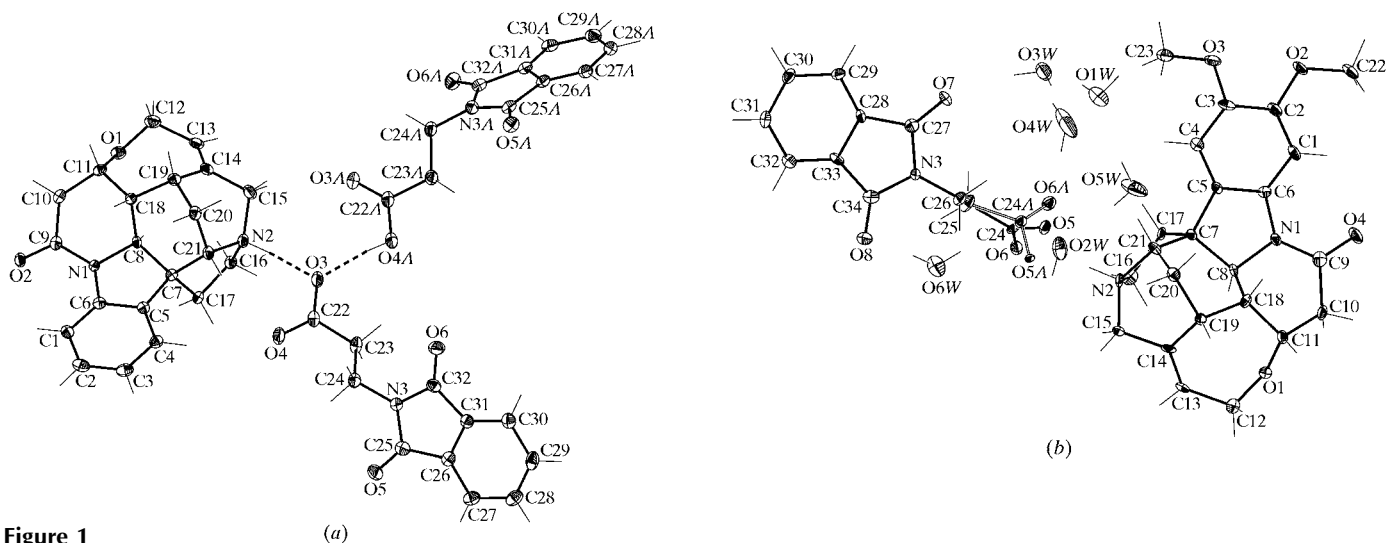
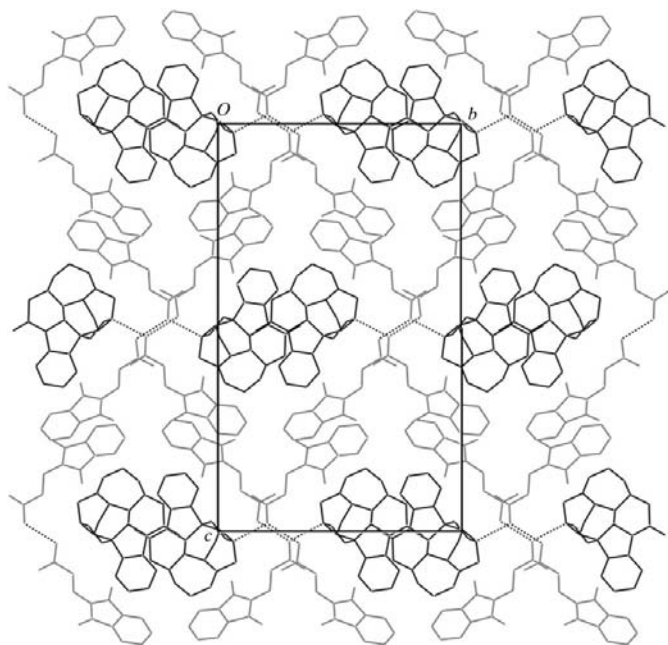


Figure 1

The molecular configuration and atom-numbering scheme in the crystal structures of (a) (1) and (b) (2). Non-H atoms are shown as 30% probability displacement ellipsoids.

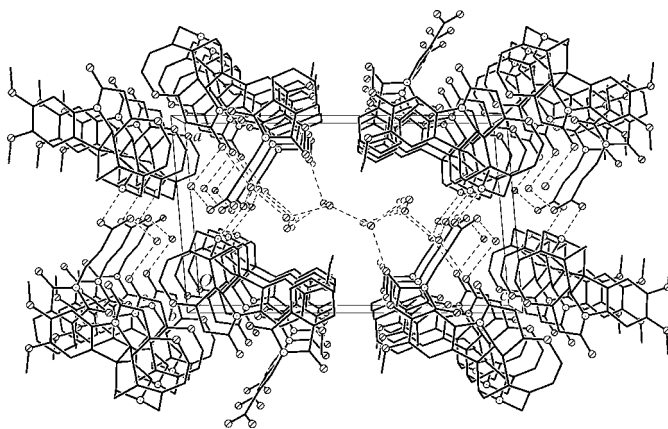
group of the  $\beta$ -alanine derivative participate in  $\pi$ - $\pi$  interactions extending along the [010] direction. Channels are present between neighboring columns resulting from this  $\pi$ - $\pi$  stacking. The shortest and longest diameters of a channel are approximately 5.25 and 11.25 Å, respectively (Fig. 3). The channels are occupied by hydrogen-bonded water molecules.

Atoms O5 and O6 of the anion, carbonyl atom O4 of the brucinium cation, and the water molecules form a hydrogen-bonded tape of type 3T6(2) (Infantes & Motherwell, 2002) that extends along the [010] direction. The 3T6(2) tape is constructed from three T6(2) tapes, linked by their edges. The



**Figure 2**

The packing of (1). *N*-Phthaloyl- $\beta$ -alaninate anions and *N*-phthaloyl- $\beta$ -alanine molecules (grey) form a three-dimensional network, with channels occupied by columns of strychninium cations extending along the [100] direction. For clarity, H atoms have been omitted.



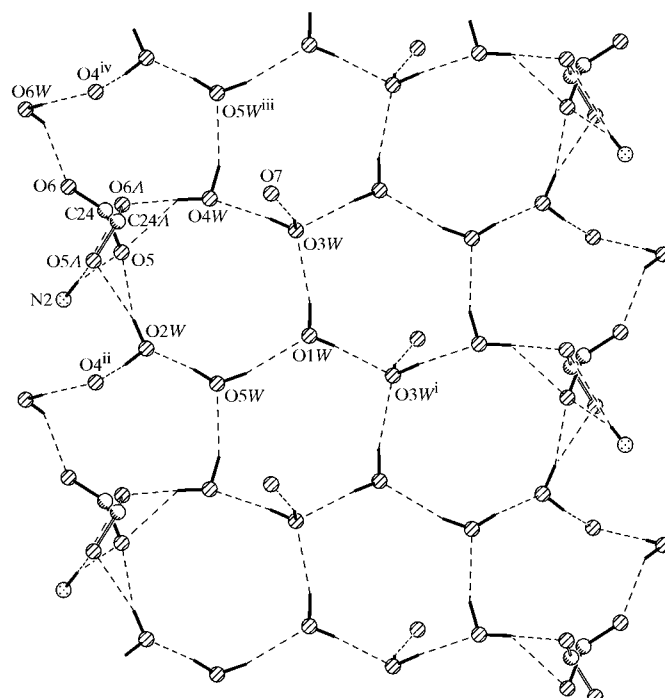
**Figure 3**

The packing of (2), showing the columnar packing of the brucinium cations. Channels, extending along the [010] direction, between consecutive brucine columns are occupied by water molecules.

T6(2) tapes are formed by six-membered rings, with neighboring six-membered rings sharing sides. The O1W, O3W, O4W and O5W water molecules, located in the central part of the channel, form one T6(2) tape, and two neighboring six-membered rings of water molecules share one side (the O1W...O3W<sup>i</sup> side; see Fig. 4). Two different six-membered rings, also linked by one side, form the other T6(2) tapes. One of these six-membered rings is formed by the O1W, O2W, O3W, O4W and O5W water molecules, as well as by the disordered carboxylate group of the *N*-phthaloyl- $\beta$ -alaninate anion either *via* atom O5 or *via* both O5A and O6A. The third cyclic hexamer involves the O2W, O4W, O5W and O6W water molecules, carbonyl atom O4 of the brucinium cation, and either atom O6A or both O5 and O6 of the disordered carboxylate group of the anion.

The resulting 3T6(2) tape is linked to atom O7 of the phthaloyl group of the *N*-phthaloyl- $\beta$ -alaninate anion. The three cyclic hexamers of the 3T6(2) tape exhibit a deformed boat conformation. The average O...O distance in the 3T6(2) tape is 2.79 Å, similar to that found in ice I<sub>h</sub> (2.759 Å at 143 K; Eisenberg & Kauzmann, 1969) and in liquid water (2.85 Å; Narten *et al.*, 1982). The water-molecule tape remains stable at room temperature. Thermogravimetric analysis shows that the crystals of (2) lose *ca* 13.5% of their weight, in one step, near 373 K, which seems to correspond to complete loss of the water of crystallization.

As mentioned above, the columnar self-assembly of strychninium cations in (1) is similar to that in (-)-strychninium (+)-neopentyl phthalate chloroform solvate (Yuan *et al.*, 1994). It is noteworthy that the columnar self-assembly of



**Figure 4**

The 3T6(2) tape in the crystal structure of (2). [Symmetry codes: (i)  $-x + 1, y + \frac{1}{2}, -z + 1$ ; (ii)  $x + 1, y, z$ ; (iii)  $x, y - 1, z$ ; (iv)  $x + 1, y - 1, z$ .] (See also Table 1.)

strychninium cations in (1) is also similar to the self-assembly of brucinium cations in brucinium *N*-phthaloyl-*L*- $\alpha$ -alaninate sesquihydrate (Białońska & Ciunik, 2004). The similarity of the crystal structures of (2) and brucinium *N*-phthaloyl-*L*- $\alpha$ -alaninate sesquihydrate is revealed in the  $\pi$ - $\pi$  stacking interactions.

In both of these crystals, the brucine arene rings, and the phthaloyl groups of the *N*-phthaloyl- $\beta$ - or *N*-phthaloyl-*L*- $\alpha$ -alaninate anions, participate in  $\pi$ - $\pi$  interactions (Table 3). Various brucine and strychnine self-assemblies in the structures under investigation are due to the presence of the two methoxy groups linked to the arene ring of brucine. Comparison of the crystal structures of the strychninium and brucinium salts with *N*-phthaloyl-*D*- and *N*-phthaloyl-*L*- $\alpha$ -alanine, as well as that with *N*-phthaloyl- $\beta$ -alanine, shows that the presence of the two methoxy groups in brucine molecules is responsible for the tendency of brucine to exhibit stacking interactions with the phthaloyl group of the  $\alpha$ - or  $\beta$ -alanine derivative;  $\pi$ - $\pi$  stacking involving brucine arene rings and guest anions is also observed in crystals of another brucinium salt (Kuwata *et al.*, 1993). This tendency to form stacks has not been observed in strychnine, which has no methoxy groups.

In summary, comparison of the crystal structures of (1) and (2) has allowed us to discover one of the differences between these alkaloids in molecular recognition. Unlike strychninium cations, brucinium cations display a greater tendency to form stacking interactions with cocrystallizing guests.

### Experimental

Crystals of (1) and (2) were obtained from ethanol solutions containing an equimolar amount of the corresponding alkaloid (commercially available) and *N*-phthaloyl- $\beta$ -alanine (Wróbel, 1983). The crystallizations were performed at room temperature by slow evaporation of the solvent.

#### Compound (1)

##### Crystal data

$C_{21}H_{23}N_2O_2^+ \cdot C_{11}H_8NO_4^-$ $C_{11}H_9NO_4$	$D_x = 1.419 \text{ Mg m}^{-3}$
$M_r = 772.79$	Mo $K\alpha$ radiation
Orthorhombic, $P2_12_12_1$	Cell parameters from 1032 reflections
$a = 7.788 (2) \text{ \AA}$	$\theta = 3.4\text{--}28.6^\circ$
$b = 16.596 (3) \text{ \AA}$	$\mu = 0.10 \text{ mm}^{-1}$
$c = 27.986 (3) \text{ \AA}$	$T = 100 (2) \text{ K}$
$V = 3617.2 (12) \text{ \AA}^3$	Block, colorless
$Z = 4$	$0.30 \times 0.30 \times 0.30 \text{ mm}$

##### Data collection

Kuma KM-4 CCD diffractometer	$R_{\text{int}} = 0.064$
$\omega$ scans	$\theta_{\text{max}} = 27.5^\circ$
24819 measured reflections	$h = -8 \rightarrow 9$
4630 independent reflections	$k = -21 \rightarrow 21$
3791 reflections with $I > 2\sigma(I)$	$l = -36 \rightarrow 35$

##### Refinement

Refinement on $F^2$	H-atom parameters constrained
$R[F^2 > 2\sigma(F^2)] = 0.051$	$w = 1/[\sigma^2(F_o^2) + (0.0474P)^2P]$
$wR(F^2) = 0.100$	where $P = (F_o^2 + 2F_c^2)/3$
$S = 1.06$	$(\Delta/\sigma)_{\text{max}} < 0.001$
4630 reflections	$\Delta\rho_{\text{max}} = 0.19 \text{ e \AA}^{-3}$
514 parameters	$\Delta\rho_{\text{min}} = -0.20 \text{ e \AA}^{-3}$

**Table 1**  
Hydrogen-bond geometry ( $\text{\AA}$ ,  $^\circ$ ) for (1).

$D\text{---}H\cdots A$	$D\text{---}H$	$H\cdots A$	$D\cdots A$	$D\text{---}H\cdots A$
$N2\text{---}H2A\cdots O3$	0.93	1.70	2.621 (3)	172
$O4A\text{---}H4A\cdots O3$	0.84	1.75	2.586 (3)	173

#### Compound (2)

##### Crystal data

$C_{23}H_{27}N_2O_4^+ \cdot C_{11}H_8NO_4^- \cdot 5.67H_2O$	$D_x = 1.384 \text{ Mg m}^{-3}$
$M_r = 715.80$	Mo $K\alpha$ radiation
Monoclinic, $P2_1$	Cell parameters from 10253 reflections
$a = 11.527 (2) \text{ \AA}$	$\theta = 3.3\text{--}28.1^\circ$
$b = 7.6690 (13) \text{ \AA}$	$\mu = 0.11 \text{ mm}^{-1}$
$c = 19.500 (3) \text{ \AA}$	$T = 100 (2) \text{ K}$
$\beta = 94.832 (14)^\circ$	Block, colorless
$V = 1717.7 (5) \text{ \AA}^3$	$0.25 \times 0.20 \times 0.20 \text{ mm}$
$Z = 2$	

##### Data collection

Kuma KM-4 CCD diffractometer	$R_{\text{int}} = 0.114$
$\omega$ scans	$\theta_{\text{max}} = 27.0^\circ$
11409 measured reflections	$h = -14 \rightarrow 14$
3937 independent reflections	$k = -8 \rightarrow 9$
2391 reflections with $I > 2\sigma(I)$	$l = -24 \rightarrow 24$

##### Refinement

Refinement on $F^2$	H-atom parameters constrained
$R[F^2 > 2\sigma(F^2)] = 0.078$	$w = 1/[\sigma^2(F_o^2) + (0.0298P)^2]$
$wR(F^2) = 0.114$	where $P = (F_o^2 + 2F_c^2)/3$
$S = 1.01$	$(\Delta/\sigma)_{\text{max}} = 0.001$
3937 reflections	$\Delta\rho_{\text{max}} = 0.24 \text{ e \AA}^{-3}$
488 parameters	$\Delta\rho_{\text{min}} = -0.28 \text{ e \AA}^{-3}$

**Table 2**  
Hydrogen-bond geometry ( $\text{\AA}$ ,  $^\circ$ ) for (2).

$D\text{---}H\cdots A$	$D\text{---}H$	$H\cdots A$	$D\cdots A$	$D\text{---}H\cdots A$
$N2\text{---}H2\cdots O5$	0.93	1.74	2.632 (8)	161
$N2\text{---}H2\cdots O5A$	0.93	1.78	2.685 (11)	164
$N2\text{---}H2\cdots O6A$	0.93	2.37	3.074 (13)	133
$O1W\text{---}H11W\cdots O3W$	0.85	1.97	2.806 (8)	168
$O1W\text{---}H12W\cdots O3W^i$	0.86	1.93	2.779 (6)	169
$O2W\text{---}H21W\cdots O4^{ii}$	0.84	2.08	2.840 (6)	151
$O2W\text{---}H22W\cdots O5A$	0.84	1.90	2.729 (13)	167
$O2W\text{---}H22W\cdots O5$	0.84	1.99	2.805 (8)	164
$O3W\text{---}H31W\cdots O7$	0.84	2.06	2.886 (5)	166
$O3W\text{---}H32W\cdots O4W$	0.85	1.90	2.738 (6)	174
$O4W\text{---}H41W\cdots O5W^{iii}$	0.89	2.04	2.860 (11)	152
$O4W\text{---}H42W\cdots O6A$	0.85	1.55	2.398 (13)	174
$O4W\text{---}H42W\cdots O5$	0.85	2.43	3.107 (9)	137
$O5W\text{---}H51W\cdots O1W$	0.85	1.96	2.786 (7)	163
$O5W\text{---}H52W\cdots O2W$	0.83	1.99	2.800 (6)	164
$O6W\text{---}H61W\cdots O6$	0.83	2.00	2.733 (9)	147
$O6W\text{---}H62W\cdots O4^{iv}$	0.83	1.98	2.790 (7)	166

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

In (2), the carboxylate group was found to be disordered over two positions, *viz.* sites C24/O5/O6 and C24A/O5A/O6A, with occupancy factors of 0.67 and 0.33, respectively. The O6W water molecule also has partial occupancy (0.67). The occupancy factors for the disordered carboxylate group of the *N*-phthaloyl- $\beta$ -alaninate anion and the O6W water molecule were initially refined but were then fixed prior to the final refinements. In both compounds, H atoms bonded to C atoms were treated as riding atoms, with C—H distances of 0.95–1.00  $\text{\AA}$ . The remaining H atoms were located in difference maps and

**Table 3** $\pi$ - $\pi$  interactions ( $\text{\AA}$ ,  $^\circ$ ) in (II).

$Cg1$  and  $Cg2$  represent the centroids of the C1–C6 and C28–C33 rings, respectively.

$CgI$	$CgJ$	$Cg \cdots Cg$	Interplanar angle	$CgI$ -perp	$CgJ$ -perp	Slippage
$Cg1$	$Cg2^v$	3.703 (4)	4.8 (3)	3.464	3.472	1.287

Notes:  $Cg \cdots Cg$  is the distance between ring centroids. The interplanar angle is that between the planes of rings  $I$  and  $J$ .  $CgI$ -perp is the perpendicular distance of  $CgI$  from ring  $J$ .  $CgJ$ -perp is the perpendicular distance of  $CgJ$  from ring  $I$ . Symmetry code: (v)  $x - 1, y + 1, z$ .

then refined with isotropic displacement parameters before being fixed prior to the final cycles of refinement. Friedel pairs were merged before the final refinement. The absolute configurations of (1) and (2) were chosen on the basis of the known absolute configurations of strychnine (Robertson & Beevers, 1951) and brucine (Toda *et al.*, 1985), respectively.

For both compounds, data collection: *CrysAlis CCD* (Oxford Diffraction, 2001); cell refinement: *CrysAlis RED* (Oxford Diffraction, 2001); data reduction: *CrysAlis RED*; program(s) used to solve structure: *SHELXS97* (Sheldrick, 1990); program(s) used to refine structure: *SHELXL97* (Sheldrick, 1997); molecular graphics: *SHELXTL-NT* (Bruker, 1999); software used to prepare material for publication: *SHELXL97*.

Supplementary data for this paper are available from the IUCr electronic archives (Reference: GD1431). Services for accessing these data are described at the back of the journal.

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