organic compounds

Forced twin-chair conformation in 7-benzoyl- and 7-phenylacetyl-r-2,c-4,t-6,t-8-tetraphenyl-3-thia-7-azabicyclo[3.3.1]nonanes with 1,3-diaxial phenyl groups in the piperidine ring: single- and double-layered supramolecular sheets built from C—H···O and C—H···π(arene) hydrogen bonds

Chinniah Sakthivel* and Ramasubbu Jeyaraman

School of Chemistry, Bharathidasan University, Tiruchirappalli, Tamil Nadu 620 024, India

Correspondence e-mail: csakthivel@gmail.com

The crystal structures of 7-benzoyl-r-2,c-4,t-6,t-8-tetraphenyl-3-thia-7-azabicyclo[3.3.1]nonane, $C_{38}H_{33}NOS$, (I), and r-2,c-4,-t-6,t-8-tetraphenyl-7-phenylacetyl-3-thia-7-azabicyclo[3.3.1]-nonane [systematic name: 2-phenyl-1-(r-2,c-4,t-6,t-8-tetra-phenyl-3-thia-7-azabicyclo[3.3.1]nonan-7-yl)ethanone], $C_{39}H_{35}$-NOS, (II), both reveal a forced twin-chair conformation with the 1,3-diaxial phenyl groups in the piperidine ring, and flattening at the N-atom end of the piperidine ring of the bicyclic system. In the crystal structure of (I), molecules are linked into sheets by a combination of two weak C—H···O and one C—H···π(arene) hydrogen bond, while in the crystal structure of (II), the molecules extend into double-layered sheets assisted by three C—H···π(arene) hydrogen bonds.

Comment

The 3,7-diheterobicyclo[3.3.1]nonane ring system offers wide conformational flexibility owing to its possible twin-chair, chair–boat, boat–chair and twin-boat conformations (Jackman *et al.*, 1982; Arjunan *et al.*, 1981; Pantaleo *et al.*, 1981; Jeyaraman & Avila, 1981). Many derivatives of 3,7-dihetero-bicyclo[3.3.1]nonanes have been found to be good class III antiarrhythmic agents (Cheema *et al.*, 2007; Garrison *et al.*, 1996; Yu *et al.*, 2006). As part of a programme studying the synthesis and stereochemistry of *N*-acyl azabicyclic systems, we have synthesized a series of *N*-acyl derivatives of 2,4,6,8-tetraphenyl-3-thia-7-azabicyclo[3.3.1]nonanes and studied their stereochemistry (Sakthivel & Jeyaraman, 2010). We report here the molecular and crystal structures of 7-benzoyl-

r-2,c-4,t-6,t-8-tetraphenyl-3-thia-7-azabicyclo[3.3.1]nonane, (I), and r-2,c-4,t-6,t-8-tetraphenyl-7-phenylacetyl-3-thia-7-azabicyclo[3.3.1]nonane, (II).
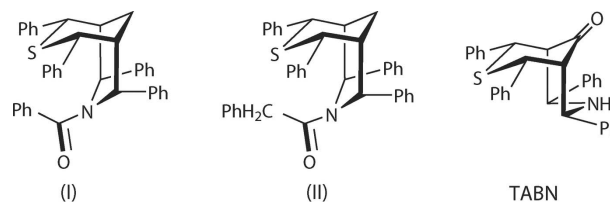
The asymmetric units of (I) and (II) each contain one molecule. The overall conformations are similar in both compounds. While the precursor of the title compounds, *viz.* r-2,c-4,t-6,t-8-tetraphenyl-3-thia-7-azabicyclo[3.3.1]nonan-9-one (TABN), is known to exist in a chair–boat conformation, with the piperidine ring of the bicyclic system in a boat form (Pantaleo *et al.*, 1981), the bicyclic compounds (I) and (II) are forced to adopt twin-chair conformations (Figs. 1 and 2) with the 1,3-diaxial phenyl groups in the piperidine ring, because of the stabilizing character of the N—C═O group, to avoid $A^{1,3}$-strain (Johnson, 1968).

In both compounds, the thiane ring is slightly distorted from an ideal chair conformation. Within this ring, the displacements of atoms C9 and S3 from the C1/C5/C4/C2 mean plane are 0.768 (2) and −0.864 (2) Å, respectively, in (I), and 0.757 (3) and −0.834 (2) Å, respectively, in (II). The C2—S3—C4 angle in the thiane ring is 98.37 (7)° in (I) and 98.79 (9)° in (II). The two phenyl substitutents in this ring prefer to occupy equatorial positions.

Unlike the thiane ring, the piperidine ring is considerably distorted from an ideal chair conformation in both compounds. Atoms C9 and N7 deviate from the C1/C5/C6/C8 mean plane by −0.699 (2) and 0.462 (2) Å, respectively, in (I), and −0.711 (3) and 0.391 (3) Å in (II). These deviations are also reflected in the ranges of the C—C bond lengths and endocyclic C—C—C bond angles observed for both compounds [1.520 (2)–1.539 (2) Å and 108.21 (1)–113.34 (1)° in (I), and 1.519 (3)–1.547 (3) Å and 109.47 (1)–114.13 (2)° in (II)]. The displacement of atom N7 from the C6/C8/C28 plane is −0.077 (2) Å in (I) and −0.074 (2) Å in (II), and the sum of the angles around N7 is 358.15 (12)° in (I) and 359.24 (14)° in (II) (Tables 1 and 3), showing that this N atom exhibits a planar character.

The acyl group prefers a coplanar orientation with respect to atoms C6 and C8, as is evident from the torsion angles C6—N7—C28—O29 and C8—N7—C28—O29 [−6.5 (2) and −175.93 (14)°, respectively, in (I), and 4.5 (3) and −165.67 (18)° in (II)]. The angles between the least-squares planes C6/N7/C8 and N7/C28/O29 are 9.39 (3) and 12.65 (3)° in (I) and (II), respectively, showing that the acyl functionality is coplanar with the C6/N7/C8 plane. The N7—C28 bond is 1.355 (2) Å in (I) and 1.366 (2) Å in (II). The contraction of this N—C bond is due to delocalization between the lone pair of electrons of the ring N atom and the hetero π electrons of the carbonyl group. As a result, the N—C bond exhibits partial
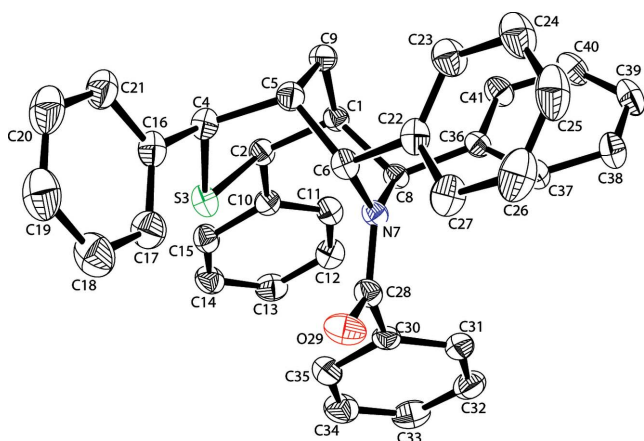
Figure 1
A view of the molecule of (I), showing the atom-numbering scheme. Displacement ellipsoids are drawn at the 30% probability level. H atoms have been omitted for clarity.

Figure 2
A view of the molecule of (II), showing the atom-numbering scheme. Displacement ellipsoids are drawn at the 30% probability level. H atoms have been omitted for clarity.
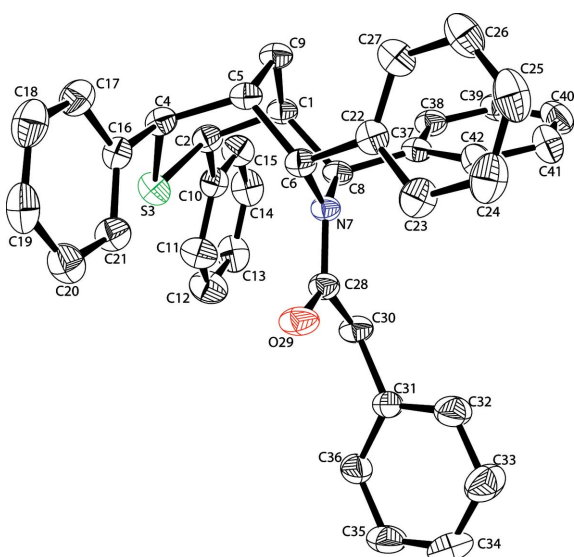

Figure 3
Part of the crystal structure of (I), showing the formation of an $R_3^2(23)$ motif that forms the ribbon along the *b* axis. For the sake of clarity, H atoms not involved in the motif shown have been omitted. [Symmetry codes: (i) $-x + 1, y - \frac{1}{2}, -z + \frac{3}{2}$; (ii) $x, y - 1, z$.]

Figure 4
Part of the crystal structure of (I), showing the C—H···π interaction, which links the ribbons shown in Fig. 2 in the *bc* plane. For the sake of clarity, H atoms not involved in the motif shown have been omitted. *Cg*1 is the centroid of the C10–C15 ring. [Symmetry code: (iii) $-x + 2, -y, -z + 2$.]

double-bond character, which leads to restricted rotation about the bond, as also found in solution NMR studies (Rogers & Woodbrey, 1962).

A comparison of the molecular structures of (I) and (II) with that of the precursor, TABN (Pantaleo *et al.*, 1981), reveals that the piperidine ring in (I) and (II) is flipped from a boat conformation to a chair in order to avoid $A^{1,3}$-strain (Johnson, 1968) caused by the interaction of the acyl group with the α,α'-diphenyl substituents. This is evidenced by the increased torsion angles about the C1—C8 and C5—C6 bonds in (I) and (II) compared with TABN (Table 5). The ring flipping causes a decrease in the N7···S3 nonbonding distances, to 3.080 (2) Å in (I) and 3.176 (2) Å in (II), compared with 3.841 Å in TABN. As a result, the lone pair–lone pair repulsion of the sp^2-hybridized atoms N7 and S3 is increased. However, severe interaction is avoided by ring flattening at the N-atom end of the piperidine ring. The
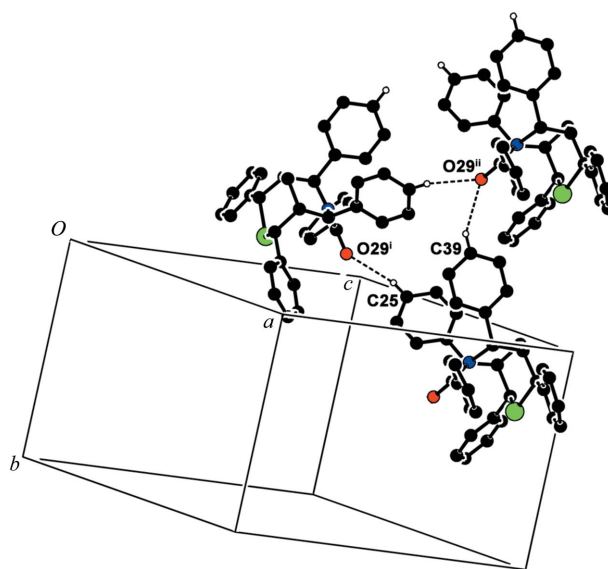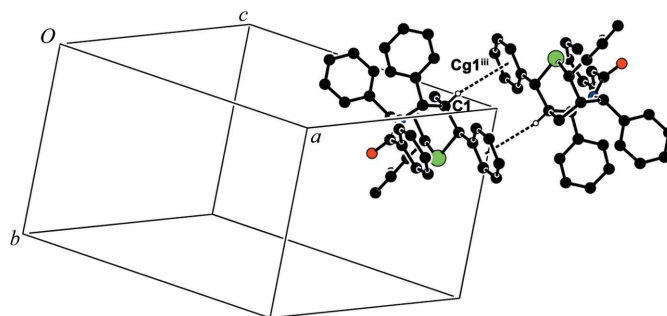
increased lone pair–lone pair repulsion of atoms N7 and S3 in (I) and (II) compared with TABN can be seen from the torsion angles about the C2—S3 and C4—S3 bonds, listed in Table 5. The N7···S3 nonbonding distances and the torsion angles about the C2—S3 and C4—S3 bonds are in agreement with the reported N3···C7 nonbonding distances and torsion angles about the C6—C7 and C8—C7 bonds of 3-acetyl- and 3-nitroso-2,4-diphenyl-3-azabicyclo[3.3.1]nonanes (Kumaran *et al.*, 1999; Priya *et al.*, 1993). Due to ring flipping, the phenyl substitutents in the piperidine rings of (I) and (II) are pushed into diaxial positions, with dihedral angles between the planes of the phenyl rings of 37.64 (8) and 66.58 (8)°, respectively. This is in agreement with the ring flipping observed in 3,7-dinitroso-2,4,6,8-tetraphenyl-3,7-diazabicyclo[3.3.1]nonan-9-one (Gdaniec *et al.*, 1997).

The crystal structure of (I) is stabilized by two weak C—H···O hydrogen-bonding interactions and one C—H···π(arene) hydrogen-bonding interaction (Table 2). The mol-
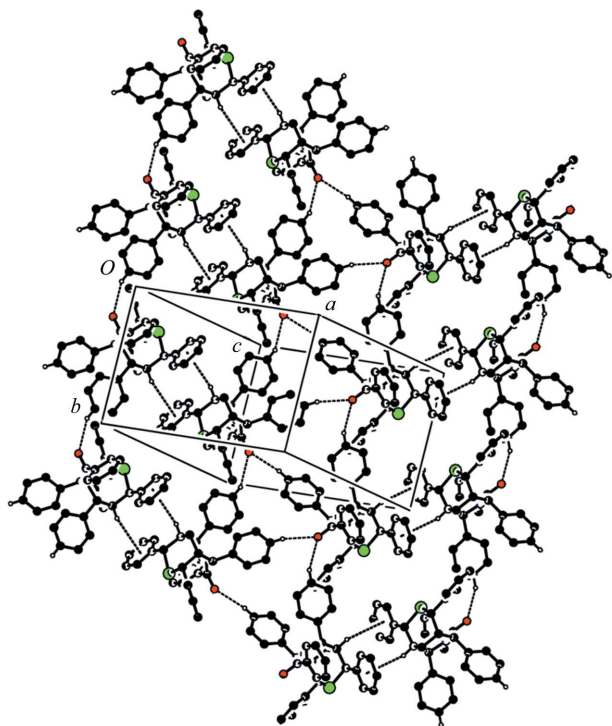
organic compounds

Figure 5
Part of the crystal structure of (I), showing the formation of the hydrogen-bonded sheet in the *bc* plane. For the sake of clarity, H atoms not involved in the motif shown have been omitted.

Figure 6
Part of the crystal structure of (II), showing the formation of the sheet in the *bc* plane. For the sake of clarity, H atoms not involved in the motifs shown have been omitted. *Cg*1 and *Cg*2 are the centroids of the C37–C42 and C22–C27 rings, respectively. [Symmetry codes: (i) x, $y + 1$, z; (ii) x, $-y + \frac{3}{2}$, $z - \frac{1}{2}$.]

ecules of (I) are linked into sheets, the formation of which can be analysed in terms of two substructural motifs formed by the individual hydrogen bonds. In the first of these motifs, the molecules are interlinked *via* intermolecular bifurcated C25—H25···O29 and C39—H39···O29 bonds, forming a cyclic $R_3^2(23)$ motif (Fig. 3) (Bernstein *et al.*, 1995). Aromatic atoms C25 and C39 in the molecule at (x, y, z) act as hydrogen-bond donors to atom O29 in the molecules at $(-x + 1, y - \frac{1}{2}, -z + \frac{3}{2})$ and $(x, y - 1, z)$, respectively. Repetition of this motif by translational symmetry then generates a ribbon along the *b* axis. Neighbouring ribbons run in an antiparallel fashion, interconnected by the second motif. In the second motif, atom C1 in the molecule at (x, y, z) acts as a hydrogen-bond donor
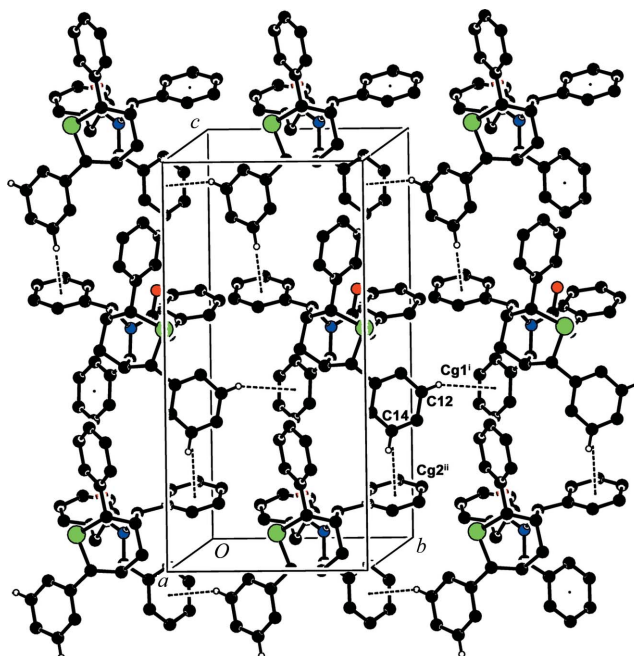
to the centroid of the aryl ring C10–C15 of the molecule at $(-x + 2, -y, -z + 2)$, and likewise, the centroid of the aryl ring C10–C15 at (x, y, z) accepts a hydrogen bond from atom C1 in the molecule at $(-x + 2, -y, -z + 2)$ (Fig. 4). The linking of the cyclic $R_3^2(23)$ motifs by C—H···π(arene) hydrogen bonds thus generates a sheet in the *bc* plane (Fig. 5). There are no interactions between adjacent sheets.

The crystal structure of (II) exhibits three types of C—H···π(arene) hydrogen bonds (Table 4). The molecules of (II) are linked into sheets by two C—H···π(arene) hydrogen bonds, and two such sheets are linked by a third C—H···π(arene) hydrogen bond to form a double-layered sheet. The whole structure can be readily analysed in terms of three
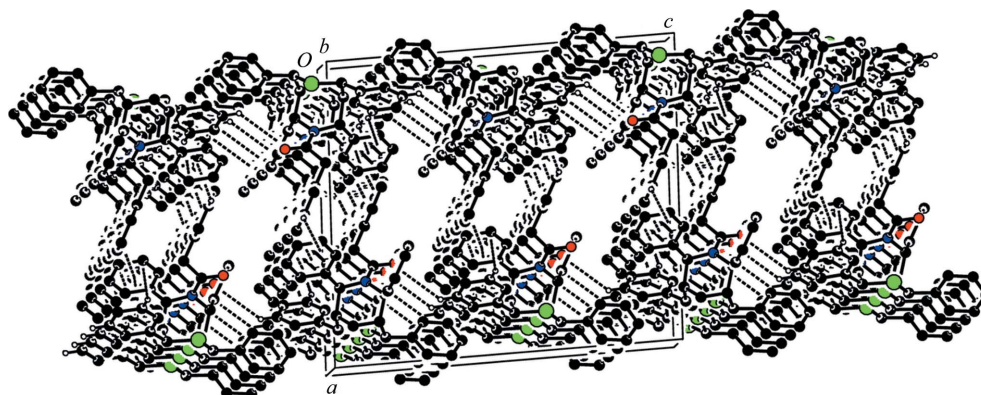

Figure 7
Part of the crystal structure of (II), showing the formation of the double-layered sheet in the *ac* plane. For the sake of clarity, H atoms not involved in the motifs shown have been omitted.

substructural motifs. In the first motif, aromatic atom C14 in the molecule at (x, y, z) acts as a hydrogen-bond donor to the centroid of the C22–C27 ring in the molecule at $(x, -y + \frac{3}{2}, z - \frac{1}{2})$. Propagation by translation of this C—H···π(arene) hydrogen bond then generates a chain running along the c axis. In the second motif, parallel chains are interlinked by another C—H···π(arene) hydrogen bond formed by aromatic atom C12 in the molecule at (x, y, z) and the centroid of the C37–C42 ring in the molecule at $(x, y + 1, z)$, thus forming a sheet in the bc plane (Fig. 6). The third substructure constitutes a double-layered sheet (Fig. 7), wherein two sheets are interlinked by the third C—H···π(arene) hydrogen bond, formed by aromatic atom C35 in the molecule at (x, y, z) and the centroid of the C37–C42 ring in the molecule at $(-x + 1, -y + 2, -z + 1)$. The double-layered sheets are arranged in the ac plane and there are no interactions between adjacent double-layered sheets.

Experimental

Compounds, (I) and (II) were synthesized from 2,4,6,8-tetraphenyl-3-thia-7-azabicyclo[3.3.1]nonane by benzoylation and phenylacetylation, respectively, in the presence of triethylamine in a dry benzene medium (Sakthivel & Jeyaraman, 2010). Crystals suitable for single-crystal X-ray diffraction [m.p.: 469–471 K for (I) and 477–479 K for (II)] were grown by slow evaporation of solutions in a benzene–hexane (1:1 v/v) mixture.

Compound (I)

Crystal data

$C_{38}H_{33}NOS$	$V = 2855.8$ (19) Å^3
$M_r = 551.72$	$Z = 4$
Monoclinic, $P2_1/c$	Mo $K\alpha$ radiation
$a = 16.139$ (5) Å	$\mu = 0.15$ mm^{-1}
$b = 10.145$ (5) Å	$T = 293$ K
$c = 17.453$ (5) Å	$0.30 \times 0.22 \times 0.18$ mm
$\beta = 92.046$ (5)°	

Data collection

Bruker Kappa APEXII CCD area-detector diffractometer	27638 measured reflections
Absorption correction: multi-scan [*SADABS* (Bruker, 2004; Blessing, 1995)]	5605 independent reflections
	4267 reflections with $I > 2\sigma(I)$
$T_{min} = 0.957$, $T_{max} = 0.974$	$R_{int} = 0.034$

Refinement

$R[F^2 > 2\sigma(F^2)] = 0.038$	370 parameters
$wR(F^2) = 0.103$	H-atom parameters constrained
$S = 1.05$	$\Delta\rho_{max} = 0.33$ e Å^{-3}
5605 reflections	$\Delta\rho_{min} = -0.24$ e Å^{-3}

Compound (II)

Crystal data

$C_{39}H_{35}NOS$	$V = 3074.2$ (2) Å^3
$M_r = 565.75$	$Z = 4$
Monoclinic, $P2_1/c$	Mo $K\alpha$ radiation
$a = 16.8724$ (7) Å	$\mu = 0.14$ mm^{-1}
$b = 9.4863$ (3) Å	$T = 293$ K
$c = 19.2376$ (8) Å	$0.24 \times 0.20 \times 0.18$ mm
$\beta = 93.245$ (1)°	

Table 1
Selected geometric parameters (Å, °) for (I).

S3—C2	1.8338 (19)	N7—C6	1.485 (2)
S3—C4	1.8186 (19)	N7—C8	1.470 (2)
O29—C28	1.227 (2)	N7—C28	1.355 (2)
C2—C1—C9	111.47 (12)	C1—C9—C5	110.08 (13)
C8—C1—C9	108.77 (12)	O29—C28—N7	122.25 (14)
S3—C2—C1	113.12 (10)	O29—C28—C30	119.28 (15)
S3—C4—C5	111.87 (12)	C2—S3—C4	98.37 (7)
C4—C5—C9	108.56 (13)	C6—N7—C8	120.12 (12)
C6—C5—C9	113.20 (13)	C6—N7—C28	117.93 (12)
N7—C6—C5	111.90 (12)	C8—N7—C28	121.10 (12)
N7—C8—C1	111.32 (12)		

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

$Cg1$ is the centroid of the C10–C15 ring.

D—H···A	D—H	H···A	D···A	D—H···A
C25—H25···O29^i	0.93	2.53	3.431 (3)	162
C39—H39···O29^{ii}	0.93	2.58	3.395 (3)	146
C1—H1···$Cg1^{iii}$	0.98	2.99	3.903 (3)	155

Symmetry codes: (i) $-x + 1, y - \frac{1}{2}, -z + \frac{3}{2}$; (ii) $x, y - 1, z$; (iii) $-x + 2, -y, -z + 2$.

Table 3
Selected geometric parameters (Å, °) for (II).

S3—C2	1.820 (2)	N7—C6	1.489 (2)
S3—C4	1.818 (2)	N7—C8	1.478 (2)
O29—C28	1.220 (2)	N7—C28	1.366 (2)
C2—C1—C9	111.93 (15)	C1—C9—C5	109.89 (15)
S3—C2—C1	113.19 (13)	O29—C28—N7	121.95 (17)
S3—C4—C5	113.16 (13)	O29—C28—C30	120.14 (17)
C4—C5—C9	110.05 (15)	C2—S3—C4	98.79 (9)
C6—C5—C9	111.35 (15)	C6—N7—C8	121.86 (14)
N7—C6—C5	112.89 (15)	C6—N7—C28	116.77 (14)
N7—C8—C1	111.61 (14)	C8—N7—C28	120.61 (14)

Data collection

Bruker Kappa APEXII CCD area-detector diffractometer	29474 measured reflections
Absorption correction: multi-scan [*SADABS* (Bruker, 2004; Blessing, 1995)]	6045 independent reflections
	4500 reflections with $I > 2\sigma(I)$
$T_{min} = 0.968$, $T_{max} = 0.976$	$R_{int} = 0.029$

Refinement

$R[F^2 > 2\sigma(F^2)] = 0.044$	379 parameters
$wR(F^2) = 0.131$	H-atom parameters constrained
$S = 1.05$	$\Delta\rho_{max} = 0.83$ e Å^{-3}
6045 reflections	$\Delta\rho_{min} = -0.20$ e Å^{-3}

All H atoms were fixed geometrically and allowed to ride on their parent C atoms, with aromatic C—H = 0.93 Å, tertiary C—H = 0.98 Å and secondary C—H = 0.97 Å, and with $U_{iso}(H) = 1.2U_{eq}(C)$. The (100) reflection for (I) was omitted from the refinement as it was completely obscured by the beam stop. Both data sets were truncated at $\theta = 26°$, as only statistically insignificant data were present above this limit. Residual electron density of 0.83 e Å^{-3} located 1.25 Å from S3 in compound (II) may be due to the presence of a small fraction of

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Table 4
Hydrogen-bond geometry (Å, °) for (II).

Cg1 and Cg2 are the centroids of the C37–C42 and C22–C27 rings, respectively.

$D-H\cdots A$	$D-H$	$H\cdots A$	$D\cdots A$	$D-H\cdots A$
C12—H12···Cg1[i]	0.93	2.95	3.811 (3)	155
C14—H14···Cg2[ii]	0.93	2.88	3.593 (3)	135
C35—H35···Cg1[iii]	0.93	2.71	3.473 (3)	140

Symmetry codes: (i) $x, y + 1, z$; (ii) $x, -y + \frac{3}{2}, z - \frac{1}{2}$; (iii) $-x + 1, -y + 2, -z + 1$.

Table 5
Comparision of torsion angles (°) in (I), (II) and TABN.

	(I)	(II)	TABN†
Thiane ring			
S3—C4—C5—C9	66.87 (15)	63.45 (18)	65.1
C9—C1—C2—S3	−59.55 (15)	−60.69 (19)	−59.6
C2—S3—C4—C5	−53.26 (13)	−50.62 (15)	−54.1
C4—S3—C2—C1	49.37 (12)	48.78 (15)	51.5
C2—C1—C9—C5	67.19 (16)	67.1 (2)	68.1
C4—C5—C9—C1	−70.44 (16)	−67.9 (2)	−71.1
Piperidine ring			
C9—C1—C8—N7	55.39 (16)	48.5 (2)	2.3
C9—C5—C6—N7	−42.75 (18)	−44.7 (2)	4.8
C6—N7—C8—C1	−45.97 (17)	−36.6 (2)	59.1
C8—N7—C6—C5	38.98 (18)	35.0 (2)	−63.2
C6—C5—C9—C1	56.34 (17)	59.6 (2)	53.6
C8—C1—C9—C5	−61.64 (16)	−61.7 (2)	−57.7
N-Acyl group			
C6—N7—C28—O29	−6.5 (2)	4.5 (3)	
C8—N7—C28—O29	−175.93 (14)	−165.67 (18)	

† Data from Pantaleo *et al.* (1981).

sulfoxide formed by oxidation of this compound. However, we were unable to find a suitable disorder model to allow us to investigate this.

For both compounds, data collection: *APEX2* (Bruker, 2004); cell refinement: *APEX2* and *SAINT* (Bruker, 2004); data reduction: *SAINT* and *XPREP* (Bruker, 2004); program(s) used to solve structure: *SHELXS97* (Sheldrick, 2008); program(s) used to refine structure: *SHELXL97* (Sheldrick, 2008); molecular graphics: *ORTEP-32* (Farrugia, 1997) and *PLATON* (Spek, 2009); software used to prepare material for publication: *PLATON* and *publCIF* (Westrip, 2010).

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