

Dartmouth College

Dartmouth Digital Commons

Dartmouth Scholarship

Faculty Work

10-2010

4-Phenylsulfonyl-2-(p-tolylsulfonyl)-1H,8H-pyrrolo[2,3-b]indole

Jeanese C. Badenock
Dartmouth College

Jason A. Jordan
Dartmouth College

Erin T. Pelkey
Dartmouth College

Gordon W. Gribble
Dartmouth College

Jerry P. Jasinski
Keene State College

Follow this and additional works at: <https://digitalcommons.dartmouth.edu/facoa>

 Part of the [Organic Chemistry Commons](#)

Dartmouth Digital Commons Citation

Badenock, Jeanese C.; Jordan, Jason A.; Pelkey, Erin T.; Gribble, Gordon W.; and Jasinski, Jerry P., "4-Phenylsulfonyl-2-(p-tolylsulfonyl)-1H,8H-pyrrolo[2,3-b]indole" (2010). *Dartmouth Scholarship*. 416. <https://digitalcommons.dartmouth.edu/facoa/416>

This Article is brought to you for free and open access by the Faculty Work at Dartmouth Digital Commons. It has been accepted for inclusion in Dartmouth Scholarship by an authorized administrator of Dartmouth Digital Commons. For more information, please contact dartmouthdigitalcommons@groups.dartmouth.edu.

4-Phenylsulfonyl-2-(*p*-tolylsulfonyl)-1*H*,8*H*-pyrrolo[2,3-*b*]indole

Jeanese C. Badenock,^a Jason A. Jordan,^a Erin T. Pelkey,^b Gordon W. Gribble^b and Jerry P. Jasinski^{c*}

^aDepartment of Biological and Chemical Sciences, University of the West Indies, Cave Hill, Barbados, ^bDepartment of Chemistry, Dartmouth College, Hanover, NH 03755-3564, USA, and ^cDepartment of Chemistry, Keene State College, 229 Main Street, Keene, NH 03435-2001, USA

Correspondence e-mail: jjasinski@keene.edu

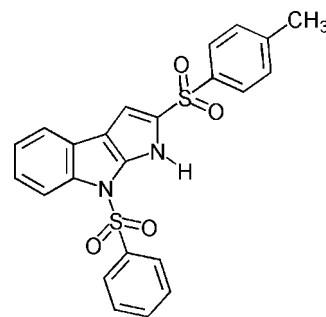
Received 15 September 2010; accepted 1 October 2010

Key indicators: single-crystal X-ray study; $T = 123$ K; mean $\sigma(\text{C}-\text{C}) = 0.002$ Å; R factor = 0.036; wR factor = 0.103; data-to-parameter ratio = 23.5.

The title compound, $\text{C}_{23}\text{H}_{18}\text{N}_2\text{O}_4\text{S}_2$, contains a pyrrolo group fused onto the plane of an indole ring with phenylsulfonyl and *p*-toluenesulfonyl groups bonded to the indole and pyrrolo rings. The angles between the mean planes of the pyrrolo-indole ring and the phenylsulfonyl and *p*-toluenesulfonyl rings are 73.7 (6) and 80.6 (0)°, respectively. The dihedral angle between the mean planes of the two benzene rings is 78.7 (4)°. In the crystal, both classical $\text{N}-\text{H}\cdots\text{O}$ and non-classical $\text{C}-\text{H}\cdots\text{O}$ intermolecular hydrogen-bonding interactions are observed, as well as weak $\pi-\pi$ interactions [centroid-centroid distances = 3.6258 (8) and 3.9298 (8) Å], which contribute to the stability of the packing.

Related literature

We have been interested in the synthesis of fused indole heterocycles (Gribble *et al.*, 2005) for the construction of more elaborate molecules, such as the potent antibiotics pyrroindomycins A and B (Abbanat *et al.*, 1999; Ding *et al.*, 1994). Both pyrrolo[2,3-*b*]indoles and pyrrolo[3,4-*b*]indoles can be synthesized in one step *via* the Barton-Zard pyrrole synthesis (Barton & Zard, 1985; Barton *et al.*, 1990) from 3-nitroindoles, depending on the *N*-indole protecting group [Pelkey *et al.*, 1996; Pelkey & Gribble, 1997, 1999, 2006]. For recent examples of the Barton-Zard pyrrole synthesis, see: Bobal & Lightner (2001); Woydziak *et al.* (2005); Larionov & deMeijere (2005); Coffin *et al.* (2006); Okujima *et al.* (2006); Ono (2008). For related structures, see: Jackson *et al.* (1975); Moody & Ward (1984*a,b*); Yamane *et al.* (1986); Yin *et al.* (2010); Tsuji *et al.* (2002); Somei *et al.* (1997); Kawasaki *et al.* (2005); Jasinski *et al.* (2010). For MOPAC theoretical calculations, see: Schmidt & Polik (2007). For standard bond lengths, see: Allen *et al.* (1987)



Experimental

Crystal data

$\text{C}_{23}\text{H}_{18}\text{N}_2\text{O}_4\text{S}_2$

$M_r = 450.51$

Triclinic, $P\bar{1}$

$a = 8.1547$ (3) Å

$b = 11.0471$ (5) Å

$c = 11.7185$ (4) Å

$\alpha = 73.834$ (4)°

$\beta = 87.131$ (3)°

$\gamma = 79.277$ (4)°

$V = 996.22$ (7) Å³

$Z = 2$

Mo $K\alpha$ radiation

$\mu = 0.30$ mm⁻¹

$T = 123$ K

$0.41 \times 0.36 \times 0.29$ mm

Data collection

Oxford Diffraction Xcalibur diffractometer with Ruby (Gemini) detector

Absorption correction: multi-scan (*CrysAlis RED*; Oxford)

Diffraction, 2007)

$T_{\min} = 0.981$, $T_{\max} = 1.000$

12580 measured reflections

6592 independent reflections

5331 reflections with $I > 2\sigma(I)$

$R_{\text{int}} = 0.020$

Refinement

$R[F^2 > 2\sigma(F^2)] = 0.036$

$wR(F^2) = 0.103$

$S = 1.09$

6592 reflections

281 parameters

H-atom parameters constrained

$\Delta\rho_{\max} = 0.52$ e Å⁻³

$\Delta\rho_{\min} = -0.33$ e Å⁻³

Table 1

Hydrogen-bond geometry (Å, °).

$D-\text{H}\cdots A$	$D-\text{H}$	$\text{H}\cdots A$	$D\cdots A$	$D-\text{H}\cdots A$
$\text{N2}-\text{H2B}\cdots\text{O3}^{\text{i}}$	0.88	2.06	2.9244 (14)	167
$\text{C13}-\text{H13A}\cdots\text{O2}^{\text{ii}}$	0.95	2.53	3.2125 (15)	129
$\text{C22}-\text{H22A}\cdots\text{O3}^{\text{i}}$	0.95	2.45	3.3786 (15)	165

Symmetry codes: (i) $-x + 1, -y, -z + 1$; (ii) $x + 1, y, z$.

Data collection: *CrysAlis PRO* (Oxford Diffraction, 2007); cell refinement: *CrysAlis PRO*; data reduction: *CrysAlis RED* (Oxford Diffraction, 2007); program(s) used to solve structure: *SHELXS97* (Sheldrick, 2008); program(s) used to refine structure: *SHELXL97* (Sheldrick, 2008); molecular graphics: *SHELXTL* (Sheldrick, 2008); software used to prepare material for publication: *SHELXTL*.

JCB wishes to thank the UWI and the Government of Barbados for funding this research. JPJ thanks Dr Ray Butcher and Howard University for assistance with the data collection and acknowledges the NSF MRI program (grant No. CHE-0619278) for funds to purchase the X-ray diffractometer.

Supplementary data and figures for this paper are available from the IUCr electronic archives (Reference: FL2319).

References

- Abbanat, D., Maiese, W. & Greenstein, M. (1999). *J. Antibiot.* **52**, 117–126.
- Allen, F. H., Kennard, O., Watson, D. G., Brammer, L., Orpen, A. G. & Taylor, R. (1987). *J. Chem. Soc. Perkin Trans. 2*, pp. S1–19.
- Barton, D. H. R., Kervagoret, J. & Zard, S. Z. (1990). *Tetrahedron*, **46**, 7587–7598.
- Barton, D. H. R. & Zard, S. Z. (1985). *J. Chem. Soc. Chem. Commun.* pp. 1098–1100.
- Bobal, P. & Lightner, D. A. (2001). *J. Heterocycl. Chem.* **38**, 527–530.
- Coffin, A. R., Roussell, M. A., Tserlin, E. & Pelkey, E. T. (2006). *J. Org. Chem.* **71**, 6678–6681.
- Ding, W., Williams, D. R., Northcote, P., Siegel, M. M., Tsao, R., Ashcroft, J., Morton, G. O., Alluri, M. & Abranat, D. (1994). *J. Antibiot.* **47**, 1250–1257.
- Gribble, G. W., Saulnier, M. G., Pelkey, E. T., Kishbaugh, T. L. S., Liu, Y. B., Jiang, J., Trujillo, H. A., Keavy, D. J., Davis, D. A., Conway, S. C., Switzer, F. L., Roy, S., Silva, R. A., Obaza-Nutaitis, J. A., Sibi, M. P., Moskalev, N. V., Barden, T. C., Chang, L., Habeski, W. M., Pelcman, B., Sponholtz, W. R., Chau, R. W., Allison, B. D., Garaas, S. D., Sinha, M. S., McGowan, M. A., Reese, M. R. & Harpp, K. S. (2005). *Curr. Org. Chem.* **9**, 1493–1519.
- Jackson, A. H., Johnston, D. N. & Shannon, P. V. R. (1975). *J. Chem. Soc. Chem. Commun.* pp. 911–912.
- Jasinski, J. P., Rinderspacher, A. & Gribble, G. W. (2010). *J. Chem. Crystallogr.* **40**, 40–47.
- Kawasaki, T., Ogawa, A., Terashima, R., Saheki, T., Ban, N., Sekiguchi, H., Sakaguchi, K. & Sakamoto, M. (2005). *J. Org. Chem.* **70**, 2957–2966.
- Larionov, O. V. & deMeijere, A. (2005). *Angew. Chem. Int. Ed.* **44**, 5664–5667.
- Moody, C. J. & Ward, J. G. (1984a). *J. Chem. Soc. Perkin Trans. 1*, pp. 2903–2909.
- Moody, C. J. & Ward, J. G. (1984b). *J. Chem. Soc. Chem. Commun.* pp. 646–647.
- Okujima, T., Jin, G., Hashimoto, Y., Yamada, H., Uno, H. & Ono, N. (2006). *Heterocycles*, **70**, 619–626.
- Ono, N. (2008). *Heterocycles*, **75**, 243–284.
- Oxford Diffraction (2007). *CrysAlis PRO* and *CrysAlis RED*. Oxford Diffraction Ltd, Abingdon, England.
- Pelkey, E. T., Chang, L. & Gribble, G. W. (1996). *Chem. Commun.* pp. 1909–1910.
- Pelkey, E. T. & Gribble, G. W. (1997). *Chem. Commun.* pp. 1873–1874.
- Pelkey, E. T. & Gribble, G. W. (1999). *Synthesis*, pp. 1117–1122.
- Pelkey, E. T. & Gribble, G. W. (2006). *Can. J. Chem.* **84**, 1338–1342.
- Schmidt, J. R. & Polik, W. F. (2007). *WebMO Pro*. WebMO, LLC, Holland, MI, USA, available from <http://www.webmo.net>.
- Sheldrick, G. M. (2008). *Acta Cryst.* **A64**, 112–122.
- Somei, M., Yamada, F., Izumi, T. & Nakajou, M. (1997). *Heterocycles*, **45**, 2327–2330.
- Tsuji, R., Nakagawa, M. & Nishida, A. (2002). *Heterocycles*, **58**, 587–593.
- Woydziak, Z. R., Boiadjev, S. E., Norona, W. S., McDonagh, A. F. & Lightner, D. A. (2005). *J. Org. Chem.* **70**, 8417–8423.
- Yamane, K., Yamamoto, H., Satoh, A., Tamura, Y. & Nozoe, T. (1986). *Bull. Chem. Soc. Jpn.* **59**, 3326–3328.
- Yin, W.-B., Yu, X., Xie, X.-L. & Li, S.-M. (2010). *Org. Biomol. Chem.* **8**, 2430–2438.

supporting information

Acta Cryst. (2010). E66, o2757–o2758 [https://doi.org/10.1107/S1600536810039425]

4-Phenylsulfonyl-2-(*p*-tolylsulfonyl)-1*H*,8*H*-pyrrolo[2,3-*b*]indole

Jeanese C. Badenock, Jason A. Jordan, Erin T. Pelkey, Gordon W. Gribble and Jerry P. Jasinski

S1. Comment

In view of our continued interest in the synthesis of fused indole heterocycles (Gribble *et al.*, 2005) for the construction of more elaborate molecules, such as the potent antibiotics pyrroindomycins A and B (Abbanat *et al.*, 1999; Ding *et al.*, 1994), we have sought to unequivocally confirm the assigned structure of the product formed in the reaction of 3-nitro-1-(phenylsulfonyl)indole with isocyanide. Our previous studies have shown that both pyrrolo[2,3-*b*]indoles and pyrrolo[3,4-*b*]indoles can be synthesized in one step *via* this Barton-Zard pyrrole synthesis (Barton & Zard, 1985; Barton *et al.*, 1990) from 3-nitroindoles depending on the *N*-indole protecting group (Pelkey *et al.*, 1996; Pelkey & Gribble, 1997, 1999, 2006). Indeed, whereas our proposed fragmentation-rearrangement sequence, to afford the pyrrolo[2,3-*b*]indole ring system (Pelkey *et al.*, 1996), only occurs with the phenylsulfonyl protecting group, the same reaction with *N*-benzyl, *N*-2-pyridyl, and *N*-ethoxycarbonyl protecting groups generates the corresponding pyrrolo[3,4-*b*]indole ring system. We differentiated these two isomers both by comparison of the NMR coupling constants and through the independent synthesis of the corresponding pyrrolo[2,3-*b*]indole. (Moody & Ward, 1984*a*, 1984*b*). To confirm this structural assignment we now report the crystal structure of the title compound, the product of the reaction of 3-nitro-1-(phenylsulfonyl)indole with tosylmethyl isocyanide, and the first crystal structure of this fused indole ring system.

The title compound contains a pyrrolo group fused onto the plane of an indole ring with phenylsulfonyl and *p*-toluenesulfonyl groups bonded to the indol and pyrrolo rings. The angles between the mean planes of the pyrrolo-indole ring and the phenylsulfonyl and *p*-toluenesulfonyl rings are 73.7 (6)° and 80.6 (0)°, respectively. The dihedral angle between the mean planes of the two benzene rings is 78.7 (4)°. The sum of the angles around the indole N atom is 345.2 (4)° indicating slightly distorted *sp*² hybridization. The C3=C10 indole bond length is 1.3760 (17)Å similar to that observed in 3-acetyl-2-ethyl-1-(phenylsulfonyl)indole (Jasinski *et al.*, 2010). The remainder of the bonds are in normal ranges (Allen *et al.*, 1987). Both classical (N—H⋯O) and non-classical (C—H⋯O) hydrogen bonding interactions are observed (Table 1, Fig. 2) as well as weak π — π interactions [$Cg1\cdots Cg3^i = 3.6258$ (8) Å; $Cg2\cdots Cg3^i = 3.9298$ (8) Å; $i = -x, 1 - y, 1 - z$; where $Cg1 = N1/C9/C4/C3/C10$; $Cg2 = N2/C1/C2/C3/C10$; $Cg3 = C4-C9$].

Following geometry optimization MOPAC (Schmidt & Polik, 2007) theoretical calculations at the AM1 level, the angles between the mean planes of the pyrrolo-indole ring and the phenylsulfonyl and *p*-toluenesulfonyl rings become 73.7 (6)° and 80.6 (0)°, respectively, and the dihedral angle between the mean planes of the two benzene rings becomes 88.6 (2)°. These observations support the influence of the hydrogen bonds and π — π interactions as contributing to the stability of crystal packing.

S2. Experimental

This compound was prepared according to the procedure of Pelkey & Gribble (2006). To a stirred solution of 3-nitro-1-(phenylsulfonyl)indole (0.50 g, 1.67 mmol, 1 eq.) in dry THF (30 ml) was added a solution of tosylmethyl isocyanide (0.39 g, 1.99 mmol, 1.20 eq.) dissolved in dry THF (15 ml) followed by the addition of DBU (0.6 ml, 4.01

mmol, 2.4 eq.). The solution was allowed to stir for 24 h at room temperature. Removal of the solvent in vacuo gave an orange oil that was purified *via* flash column chromatography (3:1 hexanes–ethyl acetate) to afford the pyrroloindole (0.46 g, 62%) as a yellow solid. Crystals suitable for the X-ray study were grown from a 1:1 mixture of CH₂Cl₂ and ether [m.p. 484–487 K; literature value 509–511 K].

S3. Refinement

All the H atoms were discernible in the difference electron density map, however, they were situated into idealized positions. The parameters of all the H atoms have been constrained within the riding atom approximation. C—H bond lengths were constrained to 0.95 or 0.98 Å for aryl or methyl H atoms, and 0.88 for N—H atoms, $U_{\text{iso}}(\text{H}) = 1.17\text{--}1.22U_{\text{eq}}(\text{C}_{\text{aryl}})$; $U_{\text{iso}}(\text{H}) = 1.51U_{\text{eq}}(\text{C}_{\text{methyl}})$ or $U_{\text{iso}}(\text{H}) = 1.16U_{\text{eq}}(\text{N})$.

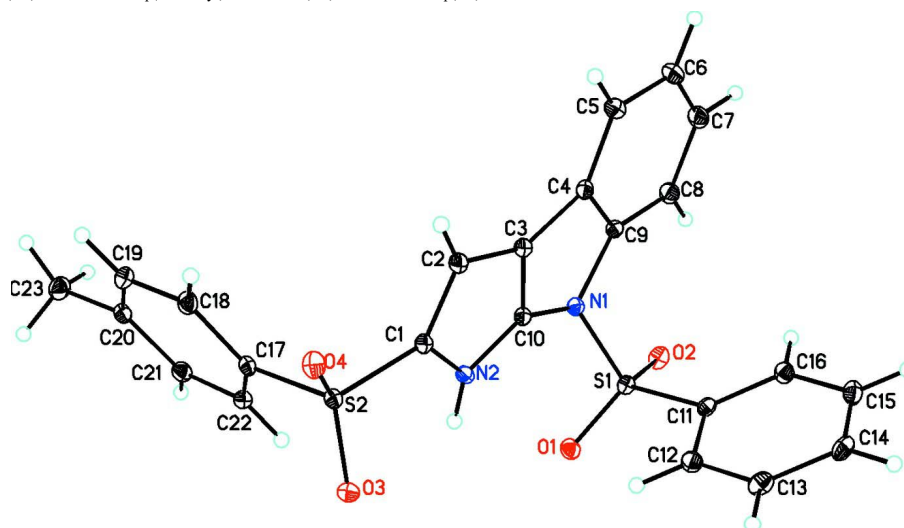


Figure 1

Molecular structure of the title compound showing the atom labeling scheme and 50% probability displacement ellipsoids.

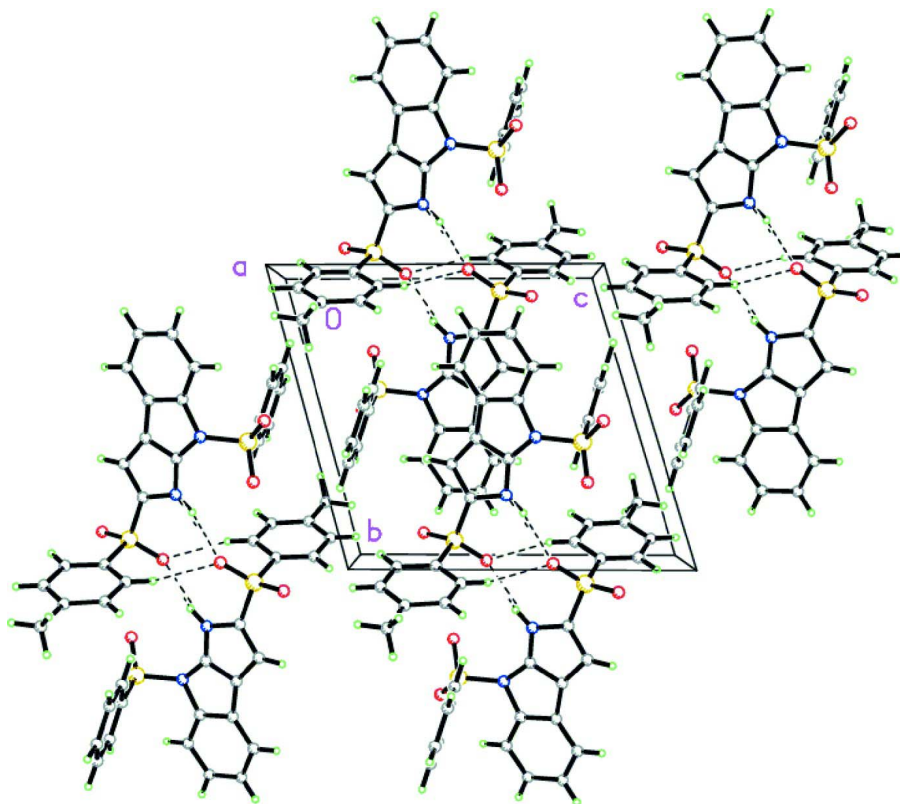


Figure 2

Packing diagram of the title compound viewed down the a axis. Dashed lines indicate classical N—H \cdots O and non-classical C—H \cdots O hydrogen bonds with a bifurcated O3 acceptor atom.

4-Phenylsulfonyl-2-(*p*-tolylsulfonyl)-1*H*,8*H*-pyrrolo[2,3-*b*]indole

Crystal data

$C_{23}H_{18}N_2O_4S_2$

$M_r = 450.51$

Triclinic, $P\bar{1}$

Hall symbol: $-P\ 1$

$a = 8.1547$ (3) Å

$b = 11.0471$ (5) Å

$c = 11.7185$ (4) Å

$\alpha = 73.834$ (4)°

$\beta = 87.131$ (3)°

$\gamma = 79.277$ (4)°

$V = 996.22$ (7) Å³

$Z = 2$

$F(000) = 468$

$D_x = 1.502$ Mg m⁻³

Mo $K\alpha$ radiation, $\lambda = 0.71073$ Å

Cell parameters from 7126 reflections

$\theta = 5.0\text{--}32.7^\circ$

$\mu = 0.30$ mm⁻¹

$T = 123$ K

Prism, colorless

$0.41 \times 0.36 \times 0.29$ mm

Data collection

Oxford Diffraction Xcalibur

diffractometer with Ruby (Gemini) detector

Radiation source: Enhance (Cu) X-ray Source

Graphite monochromator

Detector resolution: 10.5081 pixels mm⁻¹

ω scans

Absorption correction: multi-scan

(*CrysAlis RED*; Oxford Diffraction, 2007)

$T_{\min} = 0.981$, $T_{\max} = 1.000$

12580 measured reflections

6592 independent reflections

5331 reflections with $I > 2\sigma(I)$

$R_{\text{int}} = 0.020$

$$\theta_{\max} = 32.8^\circ, \theta_{\min} = 5.1^\circ$$

$$h = -11 \rightarrow 11$$

$$k = -16 \rightarrow 16$$

$$l = -17 \rightarrow 13$$

*Refinement*Refinement on F^2

Least-squares matrix: full

$$R[F^2 > 2\sigma(F^2)] = 0.036$$

$$wR(F^2) = 0.103$$

$$S = 1.09$$

6592 reflections

281 parameters

0 restraints

Primary atom site location: structure-invariant
direct methodsSecondary atom site location: difference Fourier
mapHydrogen site location: inferred from
neighbouring sites

H-atom parameters constrained

$$w = 1/[\sigma^2(F_o^2) + (0.0572P)^2 + 0.0394P]$$

$$\text{where } P = (F_o^2 + 2F_c^2)/3$$

$$(\Delta/\sigma)_{\max} < 0.001$$

$$\Delta\rho_{\max} = 0.52 \text{ e } \text{\AA}^{-3}$$

$$\Delta\rho_{\min} = -0.33 \text{ e } \text{\AA}^{-3}$$

Special details

Geometry. All e.s.d.'s (except the e.s.d. in the dihedral angle between two l.s. planes) are estimated using the full covariance matrix. The cell e.s.d.'s are taken into account individually in the estimation of e.s.d.'s in distances, angles and torsion angles; correlations between e.s.d.'s in cell parameters are only used when they are defined by crystal symmetry. An approximate (isotropic) treatment of cell e.s.d.'s is used for estimating e.s.d.'s involving l.s. planes.

Refinement. Refinement of F^2 against ALL reflections. The weighted R -factor wR and goodness of fit S are based on F^2 , conventional R -factors R are based on F , with F set to zero for negative F^2 . The threshold expression of $F^2 > \sigma(F^2)$ is used only for calculating R -factors(gt) *etc.* and is not relevant to the choice of reflections for refinement. R -factors based on F^2 are statistically about twice as large as those based on F , and R -factors based on ALL data will be even larger.

Fractional atomic coordinates and isotropic or equivalent isotropic displacement parameters (\AA^2)

	x	y	z	$U_{\text{iso}}^*/U_{\text{eq}}$
S1	0.24124 (3)	0.40940 (3)	0.21069 (3)	0.01455 (7)
S2	0.53714 (4)	0.07067 (3)	0.67939 (3)	0.01540 (7)
O1	0.28990 (11)	0.27445 (8)	0.22946 (8)	0.01961 (18)
O2	0.10331 (10)	0.48046 (9)	0.13513 (8)	0.01992 (19)
O3	0.61740 (11)	-0.00088 (8)	0.59944 (8)	0.02005 (19)
O4	0.63277 (11)	0.09255 (9)	0.76857 (8)	0.02102 (19)
N1	0.19171 (12)	0.42667 (9)	0.34605 (9)	0.01529 (19)
N2	0.36818 (12)	0.22963 (9)	0.48254 (9)	0.01541 (19)
H2B	0.3722	0.1694	0.4462	0.018*
C1	0.43829 (15)	0.21752 (11)	0.59259 (10)	0.0155 (2)
C2	0.40399 (15)	0.33305 (11)	0.62081 (11)	0.0169 (2)
H2A	0.4367	0.3501	0.6906	0.020*
C3	0.30982 (15)	0.42085 (11)	0.52414 (11)	0.0160 (2)
C4	0.21746 (15)	0.55003 (11)	0.47483 (11)	0.0161 (2)
C5	0.18616 (17)	0.66151 (12)	0.51200 (12)	0.0218 (3)
H5A	0.2306	0.6628	0.5850	0.026*
C6	0.08910 (17)	0.77060 (12)	0.44084 (12)	0.0242 (3)
H6A	0.0680	0.8471	0.4653	0.029*
C7	0.02218 (16)	0.76964 (12)	0.33428 (12)	0.0232 (3)
H7A	-0.0436	0.8457	0.2871	0.028*
C8	0.04966 (15)	0.65990 (12)	0.29554 (12)	0.0200 (2)
H8A	0.0027	0.6588	0.2233	0.024*
C9	0.14851 (14)	0.55177 (11)	0.36653 (11)	0.0159 (2)

C10	0.29295 (14)	0.35350 (11)	0.44405 (10)	0.0146 (2)
C11	0.41636 (14)	0.48258 (11)	0.16669 (10)	0.0142 (2)
C12	0.57366 (15)	0.40983 (12)	0.20143 (11)	0.0186 (2)
H12A	0.5850	0.3233	0.2480	0.022*
C13	0.71326 (15)	0.46588 (13)	0.16684 (12)	0.0214 (3)
H13A	0.8213	0.4177	0.1901	0.026*
C14	0.69552 (16)	0.59186 (13)	0.09850 (11)	0.0210 (3)
H14A	0.7918	0.6295	0.0746	0.025*
C15	0.53830 (17)	0.66374 (13)	0.06448 (12)	0.0214 (3)
H15A	0.5276	0.7502	0.0176	0.026*
C16	0.39661 (15)	0.60964 (12)	0.09882 (11)	0.0184 (2)
H16A	0.2886	0.6584	0.0764	0.022*
C17	0.37346 (15)	-0.00606 (11)	0.75228 (10)	0.0155 (2)
C18	0.34028 (16)	-0.00884 (12)	0.87037 (11)	0.0188 (2)
H18A	0.4056	0.0289	0.9110	0.023*
C19	0.21030 (16)	-0.06741 (12)	0.92891 (11)	0.0197 (2)
H19A	0.1885	-0.0706	1.0100	0.024*
C20	0.11216 (15)	-0.12121 (11)	0.86952 (11)	0.0175 (2)
C21	0.14575 (16)	-0.11501 (12)	0.74970 (11)	0.0188 (2)
H21A	0.0777	-0.1496	0.7080	0.023*
C22	0.27672 (15)	-0.05922 (11)	0.69078 (11)	0.0178 (2)
H22A	0.3001	-0.0573	0.6101	0.021*
C23	-0.02767 (17)	-0.18520 (13)	0.93246 (13)	0.0244 (3)
H23A	-0.0415	-0.1727	1.0122	0.037*
H23B	-0.0010	-0.2771	0.9388	0.037*
H23C	-0.1315	-0.1475	0.8873	0.037*

Atomic displacement parameters (Å²)

	U^{11}	U^{22}	U^{33}	U^{12}	U^{13}	U^{23}
S1	0.01309 (13)	0.01663 (14)	0.01399 (14)	-0.00350 (10)	-0.00090 (10)	-0.00358 (10)
S2	0.01639 (14)	0.01312 (13)	0.01499 (14)	-0.00131 (10)	0.00004 (10)	-0.00193 (10)
O1	0.0238 (4)	0.0173 (4)	0.0193 (4)	-0.0061 (3)	-0.0006 (3)	-0.0059 (3)
O2	0.0137 (4)	0.0273 (5)	0.0173 (4)	-0.0036 (3)	-0.0034 (3)	-0.0031 (4)
O3	0.0205 (4)	0.0163 (4)	0.0219 (5)	-0.0005 (3)	0.0043 (3)	-0.0056 (3)
O4	0.0204 (4)	0.0218 (4)	0.0201 (5)	-0.0053 (4)	-0.0037 (3)	-0.0028 (4)
N1	0.0165 (5)	0.0145 (4)	0.0133 (5)	-0.0013 (4)	0.0001 (4)	-0.0022 (4)
N2	0.0189 (5)	0.0120 (4)	0.0147 (5)	-0.0012 (4)	-0.0003 (4)	-0.0036 (4)
C1	0.0183 (5)	0.0139 (5)	0.0127 (5)	-0.0018 (4)	0.0003 (4)	-0.0017 (4)
C2	0.0211 (6)	0.0146 (5)	0.0143 (5)	-0.0028 (4)	0.0004 (4)	-0.0030 (4)
C3	0.0187 (5)	0.0139 (5)	0.0145 (5)	-0.0024 (4)	0.0018 (4)	-0.0033 (4)
C4	0.0167 (5)	0.0141 (5)	0.0156 (5)	-0.0025 (4)	0.0029 (4)	-0.0018 (4)
C5	0.0275 (7)	0.0167 (5)	0.0203 (6)	-0.0016 (5)	0.0019 (5)	-0.0054 (5)
C6	0.0270 (7)	0.0148 (6)	0.0287 (7)	0.0000 (5)	0.0040 (5)	-0.0059 (5)
C7	0.0203 (6)	0.0169 (6)	0.0271 (7)	0.0024 (5)	0.0020 (5)	-0.0014 (5)
C8	0.0175 (6)	0.0186 (6)	0.0201 (6)	0.0007 (5)	-0.0008 (4)	-0.0014 (5)
C9	0.0149 (5)	0.0143 (5)	0.0173 (6)	-0.0019 (4)	0.0040 (4)	-0.0033 (4)
C10	0.0153 (5)	0.0134 (5)	0.0139 (5)	-0.0024 (4)	0.0013 (4)	-0.0020 (4)

C11	0.0120 (5)	0.0178 (5)	0.0134 (5)	-0.0037 (4)	0.0006 (4)	-0.0046 (4)
C12	0.0160 (5)	0.0184 (5)	0.0191 (6)	-0.0007 (4)	-0.0011 (4)	-0.0029 (5)
C13	0.0129 (5)	0.0288 (7)	0.0222 (6)	-0.0022 (5)	-0.0004 (4)	-0.0073 (5)
C14	0.0178 (6)	0.0301 (7)	0.0187 (6)	-0.0112 (5)	0.0043 (4)	-0.0085 (5)
C15	0.0253 (6)	0.0202 (6)	0.0177 (6)	-0.0073 (5)	0.0011 (5)	-0.0019 (5)
C16	0.0177 (5)	0.0188 (5)	0.0165 (6)	-0.0016 (4)	-0.0013 (4)	-0.0019 (4)
C17	0.0171 (5)	0.0114 (5)	0.0153 (5)	-0.0007 (4)	0.0000 (4)	-0.0006 (4)
C18	0.0227 (6)	0.0174 (5)	0.0153 (6)	-0.0035 (5)	-0.0030 (4)	-0.0024 (4)
C19	0.0235 (6)	0.0200 (6)	0.0141 (6)	-0.0035 (5)	0.0010 (4)	-0.0026 (4)
C20	0.0190 (6)	0.0128 (5)	0.0184 (6)	-0.0013 (4)	0.0013 (4)	-0.0018 (4)
C21	0.0226 (6)	0.0151 (5)	0.0197 (6)	-0.0041 (4)	-0.0003 (5)	-0.0057 (4)
C22	0.0224 (6)	0.0148 (5)	0.0153 (6)	-0.0012 (4)	0.0018 (4)	-0.0044 (4)
C23	0.0258 (7)	0.0244 (6)	0.0241 (7)	-0.0098 (5)	0.0058 (5)	-0.0062 (5)

Geometric parameters (Å, °)

S1—O1	1.4263 (9)	C8—H8A	0.9500
S1—O2	1.4316 (9)	C11—C16	1.3914 (16)
S1—N1	1.6707 (10)	C11—C12	1.3941 (16)
S1—C11	1.7557 (12)	C12—C13	1.3856 (18)
S2—O4	1.4322 (9)	C12—H12A	0.9500
S2—O3	1.4455 (9)	C13—C14	1.3839 (19)
S2—C1	1.7300 (12)	C13—H13A	0.9500
S2—C17	1.7701 (12)	C14—C15	1.3889 (18)
N1—C10	1.4084 (15)	C14—H14A	0.9500
N1—C9	1.4446 (15)	C15—C16	1.3895 (18)
N2—C10	1.3506 (14)	C15—H15A	0.9500
N2—C1	1.3990 (15)	C16—H16A	0.9500
N2—H2B	0.8800	C17—C18	1.3896 (17)
C1—C2	1.3818 (17)	C17—C22	1.3970 (17)
C2—C3	1.4184 (17)	C18—C19	1.3958 (17)
C2—H2A	0.9500	C18—H18A	0.9500
C3—C10	1.3760 (17)	C19—C20	1.3932 (18)
C3—C4	1.4567 (16)	C19—H19A	0.9500
C4—C5	1.3937 (18)	C20—C21	1.4022 (17)
C4—C9	1.4075 (17)	C20—C23	1.5065 (17)
C5—C6	1.3877 (18)	C21—C22	1.3897 (17)
C5—H5A	0.9500	C21—H21A	0.9500
C6—C7	1.391 (2)	C22—H22A	0.9500
C6—H6A	0.9500	C23—H23A	0.9800
C7—C8	1.3861 (19)	C23—H23B	0.9800
C7—H7A	0.9500	C23—H23C	0.9800
C8—C9	1.3871 (16)		
O1—S1—O2	121.13 (6)	N2—C10—C3	111.89 (11)
O1—S1—N1	104.32 (5)	N2—C10—N1	134.91 (11)
O2—S1—N1	106.30 (5)	C3—C10—N1	112.99 (10)
O1—S1—C11	109.10 (5)	C16—C11—C12	121.61 (11)

O2—S1—C11	109.09 (5)	C16—C11—S1	120.24 (9)
N1—S1—C11	105.77 (5)	C12—C11—S1	118.15 (9)
O4—S2—O3	120.17 (6)	C13—C12—C11	118.89 (11)
O4—S2—C1	108.32 (6)	C13—C12—H12A	120.6
O3—S2—C1	107.11 (6)	C11—C12—H12A	120.6
O4—S2—C17	107.49 (6)	C14—C13—C12	120.11 (12)
O3—S2—C17	107.91 (6)	C14—C13—H13A	119.9
C1—S2—C17	104.84 (6)	C12—C13—H13A	119.9
C10—N1—C9	103.92 (10)	C13—C14—C15	120.63 (12)
C10—N1—S1	119.83 (8)	C13—C14—H14A	119.7
C9—N1—S1	121.49 (8)	C15—C14—H14A	119.7
C10—N2—C1	105.31 (10)	C14—C15—C16	120.20 (12)
C10—N2—H2B	127.3	C14—C15—H15A	119.9
C1—N2—H2B	127.3	C16—C15—H15A	119.9
C2—C1—N2	110.47 (10)	C15—C16—C11	118.56 (11)
C2—C1—S2	128.02 (10)	C15—C16—H16A	120.7
N2—C1—S2	121.31 (9)	C11—C16—H16A	120.7
C1—C2—C3	105.85 (11)	C18—C17—C22	120.89 (11)
C1—C2—H2A	127.1	C18—C17—S2	118.71 (10)
C3—C2—H2A	127.1	C22—C17—S2	120.37 (9)
C10—C3—C2	106.48 (10)	C17—C18—C19	119.56 (12)
C10—C3—C4	106.28 (10)	C17—C18—H18A	120.2
C2—C3—C4	147.16 (12)	C19—C18—H18A	120.2
C5—C4—C9	118.78 (11)	C20—C19—C18	120.61 (12)
C5—C4—C3	134.52 (12)	C20—C19—H19A	119.7
C9—C4—C3	106.70 (10)	C18—C19—H19A	119.7
C6—C5—C4	119.01 (13)	C19—C20—C21	118.85 (11)
C6—C5—H5A	120.5	C19—C20—C23	120.83 (11)
C4—C5—H5A	120.5	C21—C20—C23	120.31 (12)
C5—C6—C7	121.04 (12)	C22—C21—C20	121.23 (12)
C5—C6—H6A	119.5	C22—C21—H21A	119.4
C7—C6—H6A	119.5	C20—C21—H21A	119.4
C8—C7—C6	121.29 (12)	C21—C22—C17	118.83 (11)
C8—C7—H7A	119.4	C21—C22—H22A	120.6
C6—C7—H7A	119.4	C17—C22—H22A	120.6
C7—C8—C9	117.26 (12)	C20—C23—H23A	109.5
C7—C8—H8A	121.4	C20—C23—H23B	109.5
C9—C8—H8A	121.4	H23A—C23—H23B	109.5
C8—C9—C4	122.62 (11)	C20—C23—H23C	109.5
C8—C9—N1	127.30 (11)	H23A—C23—H23C	109.5
C4—C9—N1	110.05 (10)	H23B—C23—H23C	109.5
O1—S1—N1—C10	42.28 (10)	C2—C3—C10—N2	0.36 (14)
O2—S1—N1—C10	171.37 (9)	C4—C3—C10—N2	-177.43 (10)
C11—S1—N1—C10	-72.74 (10)	C2—C3—C10—N1	175.95 (10)
O1—S1—N1—C9	174.84 (9)	C4—C3—C10—N1	-1.84 (13)
O2—S1—N1—C9	-56.07 (10)	C9—N1—C10—N2	176.61 (13)
C11—S1—N1—C9	59.82 (10)	S1—N1—C10—N2	-43.72 (18)

C10—N2—C1—C2	0.64 (13)	C9—N1—C10—C3	2.39 (13)
C10—N2—C1—S2	175.91 (9)	S1—N1—C10—C3	142.06 (9)
O4—S2—C1—C2	-20.80 (13)	O1—S1—C11—C16	154.12 (10)
O3—S2—C1—C2	-151.78 (11)	O2—S1—C11—C16	19.79 (12)
C17—S2—C1—C2	93.73 (12)	N1—S1—C11—C16	-94.18 (11)
O4—S2—C1—N2	164.83 (9)	O1—S1—C11—C12	-25.73 (11)
O3—S2—C1—N2	33.85 (11)	O2—S1—C11—C12	-160.07 (10)
C17—S2—C1—N2	-80.63 (10)	N1—S1—C11—C12	85.96 (11)
N2—C1—C2—C3	-0.43 (14)	C16—C11—C12—C13	-0.25 (19)
S2—C1—C2—C3	-175.30 (9)	S1—C11—C12—C13	179.61 (10)
C1—C2—C3—C10	0.05 (13)	C11—C12—C13—C14	-0.3 (2)
C1—C2—C3—C4	176.14 (18)	C12—C13—C14—C15	0.4 (2)
C10—C3—C4—C5	179.76 (14)	C13—C14—C15—C16	0.0 (2)
C2—C3—C4—C5	3.7 (3)	C14—C15—C16—C11	-0.49 (19)
C10—C3—C4—C9	0.47 (13)	C12—C11—C16—C15	0.64 (19)
C2—C3—C4—C9	-175.62 (18)	S1—C11—C16—C15	-179.22 (10)
C9—C4—C5—C6	-0.39 (18)	O4—S2—C17—C18	12.96 (11)
C3—C4—C5—C6	-179.62 (13)	O3—S2—C17—C18	143.93 (9)
C4—C5—C6—C7	0.5 (2)	C1—S2—C17—C18	-102.15 (10)
C5—C6—C7—C8	0.1 (2)	O4—S2—C17—C22	-168.94 (9)
C6—C7—C8—C9	-0.90 (19)	O3—S2—C17—C22	-37.97 (11)
C7—C8—C9—C4	1.05 (18)	C1—S2—C17—C22	75.95 (11)
C7—C8—C9—N1	178.71 (12)	C22—C17—C18—C19	1.07 (17)
C5—C4—C9—C8	-0.41 (18)	S2—C17—C18—C19	179.16 (9)
C3—C4—C9—C8	179.01 (11)	C17—C18—C19—C20	-1.00 (18)
C5—C4—C9—N1	-178.44 (11)	C18—C19—C20—C21	-0.28 (18)
C3—C4—C9—N1	0.99 (13)	C18—C19—C20—C23	179.65 (11)
C10—N1—C9—C8	-179.91 (11)	C19—C20—C21—C22	1.53 (18)
S1—N1—C9—C8	41.26 (16)	C23—C20—C21—C22	-178.40 (11)
C10—N1—C9—C4	-2.01 (12)	C20—C21—C22—C17	-1.47 (18)
S1—N1—C9—C4	-140.84 (9)	C18—C17—C22—C21	0.15 (17)
C1—N2—C10—C3	-0.61 (13)	S2—C17—C22—C21	-177.91 (9)
C1—N2—C10—N1	-174.88 (12)		

Hydrogen-bond geometry (\AA , $^\circ$)

$D-H\cdots A$	$D-H$	$H\cdots A$	$D\cdots A$	$D-H\cdots A$
N2—H2B \cdots O3 ⁱ	0.88	2.06	2.9244 (14)	167
C13—H13A \cdots O2 ⁱⁱ	0.95	2.53	3.2125 (15)	129
C22—H22A \cdots O3 ⁱ	0.95	2.45	3.3786 (15)	165

Symmetry codes: (i) $-x+1, -y, -z+1$; (ii) $x+1, y, z$.