Two *N*-(2-phenylethyl)nitroaniline derivatives as precursors for slow and sustained nitric oxide release agents

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Notwithstanding its simple structure, the chemistry of nitric oxide (NO) is complex. As a radical, NO is highly reactive. NO also has profound effects on the cardiovascular system. In order to regulate NO levels, direct therapeutic interventions include the development of numerous NO donors. Most of these donors release NO in a single high-concentration burst, which is deleterious. *N*-Nitrosated secondary amines release NO in a slow, sustained, and rate-tunable manner. Two new precursors to sustained NO-releasing materials have been characterized. *N*-[2-(3,4-Dimethoxyphenyl)ethyl]-2,4-dinitroaniline, C₁₆H₁₇N₃O₆, (I), crystallizes with one independent molecule in the asymmetric unit. The adjacent amine and nitro groups form an intramolecular N—H···O hydrogen bond. The *anti* conformation about the phenylethyl-to-aniline C—N bond leads to the planes of the arene and aniline rings being approximately perpendicular. Molecules are linked into dimers by weak intermolecular N—H···O hydrogen bonds such that each amine H atom participates in a three-center interaction with two nitro O atoms. The dimers pack so that the arene rings of adjacent molecules are not parallel and π – π interactions do not appear to be favored. *N*-(4-Methylsulfonyl-2-nitrophenyl)-L-phenylalanine, C₁₆H₁₆N₂O₆S, (II), with an optically active center, also crystallizes with one unique molecule in the asymmetric unit. The L enantiomer was established *via* the configuration of the starting material and was confirmed by refinement of the Flack parameter. As in (I), there is an intramolecular N—H···O hydrogen bond between adjacent amine and nitro groups. The conformation of the molecule is such that the arene rings display a dihedral angle of *ca* 60°. Unlike (I), molecules are not linked *via* intermolecular N—H···O hydrogen bonds. Rather, the carboxylic acid H atom forms a classic, approximately linear, O—H···O hydrogen bond with a sulfone O atom. Pairs of molecules related by twofold rotation axes are linked into dimers by two such interactions. The packing pattern features a zigzag arrangement of the arene rings without apparent π – π interactions. These structures are compared with reported analogues, revealing significant differences in molecular conformation, intermolecular interactions, and packing that result from modest changes in functional groups. The structures are discussed in terms of potential NO-release capability.

1. Introduction

Nitrogen monoxide, commonly known as nitric oxide (NO), is produced *in vivo* from L-arginine (Miller & Megson, 2007). The conversion of L-arginine to NO and citrulline is catalyzed by nitric oxide synthases along with a series of cofactors. Notwithstanding its simple structure, the chemistry of NO is complex. As a radical, NO is highly reactive and it is consumed quickly within a radius of 100 μ m. Therefore NO, which has profound effects on the cardiovascular system, must be produced slowly in small fluxes at the inner walls of blood vessels by endothelial cells (Zhou *et al.*, 2006).

Since the discovery of the vaso-relaxing effects of NO (Cauwels, 2007), its physiological impact on the cardiovascular system has been the most studied. Endothelial cells, which line the lumen of the blood vessels, produce NO from L-arginine. The conversion is catalyzed by endothelial nitric oxide synthase (eNOS). The lypophilicity, small size, and chemical lability of NO allows for easy passage through cell membranes, without the use of channels or receptors, to neighboring cells (Miller *et al.*, 2004). The effects of NO on the underlying vascular smooth muscle cells (VSMC) include vasodilation and inhibition of VSMC proliferation, as well as its migration to the endothelial layer (Jeremy *et al.*, 1999).

The salutary roles of NO in the functioning of the cardiovascular, nervous, respiratory, and immune systems, in addition to its protecting functions of the heart, brain, and kidneys, have been well documented (Jobgen *et al.*, 2006). On the other hand, high NO concentrations cause apoptosis and other complications, including septic and hemorrhagic shock, multiple sclerosis, neurodegenerative diseases, rheumatoid arthritis, ulcerative colitis, and cancer (Jeremy *et al.*, 1999; Lundberg *et al.*, 2015). A wide variety of diseases and disorders have been ascribed to NO malfunctions. These maladies include endothelial dysfunction, hypertension, cardiovascular disease, asthma, pulmonary hypertension, erectile dysfunction, pre-eclampsia, and insulin resistance (Giles, 2006). The overall effects on the cardiovascular system can lead to further endothelial injury and atherosclerosis (Stasch *et al.*, 2011).

In order to better regulate NO levels, several recommendations have been made, which include a polyphenol-rich diet (Anter *et al.*, 2004), moderate alcohol consumption (Lucas *et al.*, 2005), and regular exercise (Hambrecht *et al.*, 2003). Direct therapeutic interventions include the development of numerous NO donors. Most of these donors release NO in a single high-concentration burst, which is deleterious (Cai *et al.*, 2005). We have reported a series of *N*-nitrosated secondary amines that release NO in a slow, sustained, and rate-tunable manner (Wang *et al.*, 2009; Yu *et al.*, 2011; Curtis *et al.*, 2013, 2014; Lagoda *et al.*, 2014). Furthermore, the released NO has been shown to inhibit the proliferation of human aortic smooth muscle cells, a contributing factor to the progression of atherosclerosis (Yu *et al.*, 2011; Curtis *et al.*, 2013).

We report herein the syntheses and X-ray crystal structures of two secondary amines, the precursors to NO donors. These secondary amines, namely *N*-[2-(3,4-dimethoxyphenyl)ethyl]-2,4-dinitroaniline, (I), and *N*-(4-methylsulfonyl-2-nitrophenyl)-L-phenylalanine, (II), differ in their hydrophilic and lipophilic balances (HLBs). We hypothesize that the HLB of an NO donor will play a crucial role in the overall NO release rates of these compounds in an aqueous medium (phosphate-buffered saline solution). Compound (I) was prepared by the reaction of 3,4-dimethoxyphenethylamine and an activated aromatic monofluoride, *i.e.* 2,4-dinitrofluorobenzene. The synthesis of (II) was accomplished by the reaction of L-phenylalanine with 4-methylsulfonyl-2-nitrofluorobenzene.

2. Experimental

2.1. Synthesis and crystallization

For the synthesis of (I), sodium bicarbonate (0.373 g, 4.44 mmol), 3,4-dimethoxyphenethylamine (97%) (0.539 g, 2.88 mmol), and 2,4-dinitrofluorobenzene (0.536 g, 2.88 mmol) were weighed separately in glass vials and transferred to a 50 ml round-bottomed flask equipped with a magnetic stirrer bar. The vials were rinsed with *N,N*-dimethylacetamide (DMAC, 10 ml) and the rinses transferred to the reaction vessel. The reaction mixture was allowed to stir at room temperature for 1 h, after which time the mixture was poured onto a saturated sodium chloride solution (100 ml) to precipitate the crude product. The crude product was extracted with dichloromethane (75 ml) and washed twice with deionized water (100 ml). The organic layer was dried over anhydrous magnesium sulfate, followed by gravity filtration. The solvent was evaporated under reduced pressure using a rotary evaporator. The crude product, an orange solid, was recrystallized from a dichloromethane–diethyl ether solution (1:1 *v/v*) as crystals suitable for X-ray diffraction (yield 55%; m.p. 379–380 K). ^1H NMR (300 MHz, CDCl_3): δ 9.10 (*d*, 1H), 8.57 (*s*, 1H), 8.24 (*m*, 1H), 6.84 (*m*, 4H), 3.89 (*s*, 3H), 3.86 (*s*, 3H), 3.64 (*q*, 2H), 3.02 (*t*, 2H); ^{13}C NMR (300 MHz, CDCl_3): δ 149.29, 148.13, 148.12, 136.01, 130.29, 129.66, 124.54, 120.71, 113.85, 111.68, 111.57, 55.88, 45.10, 34.50; IR (NaCl, ν , cm^{-1}): 3357, 3107, 2934, 1621, 1590, 1517, 1465, 1423, 1335, 1305, 1263, 1238, 1196, 1144, 1084, 1027; MS (*m/z*) (% base peak): 347 (8), 281 (5), 207 (18), 166 (22), 151 (100), 137 (8), 107 (11), 77 (16).

Compound (II) was prepared by dissolving 4-methylsulfonyl-2-nitrofluorobenzene (0.565 g, 2.58 mmol) in tetrahydrofuran (THF, 15 ml) in a 100 ml round-bottomed flask equipped with a magnetic stirrer bar in the presence of sodium bicarbonate (2.185 g, 24.6 mmol). The reaction mixture turned yellow upon the addition of sodium bicarbonate. L-Phenylalanine (0.406 g, 2.46 mmol) was dissolved in deionized water (25 ml) in a 50 ml beaker and the solution was subsequently transferred into the reaction vessel using a funnel. Water (5 ml) was used to wash the funnel. The reaction vessel was fitted with an air condenser and the mixture was allowed to stir at room temperature for 12 h, after which time the THF was removed under reduced pressure using a rotatory evaporator.

Table 1
Experimental details.

	(I)	(II)
Crystal data		
Chemical formula	$C_{16}H_{17}N_3O_6$	$C_{16}H_{16}N_2O_6S$
M_r	347.33	364.38
Crystal system, space group	Monoclinic, $P2_1/c$	Monoclinic, $C2$
Temperature (K)	173	173
a, b, c (Å)	13.0087 (12), 7.2092 (6), 17.0024 (16)	21.260 (3), 5.7264 (6), 14.2762 (16)
β (°)	101.297 (7)	103.456 (7)
V (Å ³)	1563.6 (3)	1690.3 (4)
Z	4	4
Radiation type	Mo $K\alpha$	Mo $K\alpha$
μ (mm ⁻¹)	0.12	0.23
Crystal size (mm)	0.30 × 0.23 × 0.11	0.80 × 0.14 × 0.04
Data collection		
Diffractometer	Rigaku XtaLAB mini	Rigaku XtaLAB mini
Absorption correction	Multi-scan (<i>REQAB</i> ; Rigaku, 1998)	Multi-scan (<i>REQAB</i> ; Rigaku, 1998)
$T_{\min}$, $T_{\max}$	0.828, 0.987	0.815, 0.991
No. of measured, independent and observed reflections	16236, 3578, 2913 [$F^2 > 2.0\sigma(F^2)$]	10478, 4851, 4201 [$I > 2\sigma(I)$]
R_{int}	0.030	0.029
$(\sin \theta/\lambda)_{\text{max}}$ (Å ⁻¹)	0.649	0.704
Refinement		
$R[F^2 > 2\sigma(F^2)]$, $wR(F^2)$, S	0.039, 0.102, 1.04	0.039, 0.092, 1.03
No. of reflections	3578	4851
No. of parameters	232	235
No. of restraints	0	1
H-atom treatment	H atoms treated by a mixture of independent and constrained refinement	H atoms treated by a mixture of independent and constrained refinement
$\Delta\rho_{\text{max}}$, $\Delta\rho_{\text{min}}$ (e Å ⁻³)	0.25, -0.21	0.30, -0.29
Absolute structure	—	Flack x determined using 1620 quotients $[(I^+) - (I^-)]/[(I^+) + (I^-)]$ (Parsons <i>et al.</i> , 2013)
Absolute structure parameter	—	0.01 (4)

Computer programs: *CrystalClear-SM Expert* (Rigaku, 2011), *SHELXS97* (Sheldrick, 2008), *SHELXL97* (Sheldrick, 2008), *SHELXL2014* (Sheldrick, 2015), *CrystalMaker* (Palmer, 2013) and *CrystalStructure* (Rigaku, 2010).

The resulting aqueous solution was washed with diethyl ether (50 ml) to remove excess starting material. The crude product was precipitated *via* acidification of the aqueous solution (pH *ca* 2) using 12 *M* hydrochloric acid. The precipitated crude product was extracted using ethyl acetate (50 ml), which was collected and washed with deionized water (50 ml) three times. The organic layer containing the crude product was dried over anhydrous magnesium sulfate, followed by gravity filtration. The solvent was removed using a rotary evaporator to yield a bright yellow solid. Crystals suitable for X-ray diffraction were obtained by recrystallization from a di-

chloromethane–hexane solution (4:1 *v/v*) (yield 58%; m.p. 443–445 K). ¹H NMR (300 MHz, DMSO-*d*₆): δ 8.58 (*d*, 1H), 8.50 (*d*, 1H), 7.92 (*dd*, 1H), 7.27–7.15 (overlapping peaks, 6H), 4.94 (*q*, 1H), 3.24 (*d*, 2H), 3.20 (*s*, 3H); ¹³C NMR (300 MHz, DMSO-*d*₆): δ 172.25, 146.61, 136.40, 134.13, 130.82, 129.84, 128.83, 127.75, 127.40, 127.35, 116.67, 56.33, 44.09, 37.04; IR (solid, ν , cm⁻¹): 3379, 3176, 3090, 1733, 1611, 1518, 1367, 1299, 1145; ESI-MS (*m/z*) calculated for $C_{16}H_{16}N_2O_6S$ [$M - H$]⁻ 363.38, found 363.03.

2.2. Refinement

Crystal data, data collection and structure refinement details are summarized in Table 1. H atoms on C atoms were included in calculated positions as riding atoms, with C–H bond lengths of 0.95 (aryl), 0.98 (methyl), 0.99 (methylene) and 1.00 Å (methine). H atoms on N and O atoms were located from difference Fourier syntheses and were refined isotropically without any restraints (see the N–H and O–H distances in Tables 2 and 3). For (II), the Flack x parameter was determined (Table 1), and the probability $P2 = 1.000$, $G = 0.97$ (8), and a Hooft y parameter of 0.02 (3) were determined from an analysis of the Bijvoet differences (Hooft *et al.*, 2008). We acknowledge that the crystal of (II) was longer than optimal, but the needles were difficult to cut cleanly and the refinement results do not appear to have been adversely affected.

Figure 1
The molecular structure of (I), showing the atom-labeling scheme and 70% probability displacement ellipsoids for the non-H atoms. The intramolecular hydrogen bond is shown as a dashed line.

3. Results and discussion

N-[2-(3,4-Dimethoxyphenyl)ethyl]-2,4-dinitroaniline, (I), crystallizes in the monoclinic space group $P2_1/c$ with one independent molecule in the asymmetric unit (Fig. 1). The adjacent amine and nitro groups form an intramolecular $N-H\cdots O$ hydrogen bond (Table 2) consistent with previous observations in molecules of this type (Wade *et al.*, 2013; Payne *et al.*, 2010; Gangopadhyay & Radhakrishnan, 2000; Clegg *et al.*, 1994; Panunto *et al.*, 1987). Aniline (I) is chemically very similar to 2,4-dinitro-*N*-(2-phenylethyl)aniline, (III), whose structure we reported recently (Wade *et al.*, 2013), with (I) differing only in the presence of the methoxy groups in the 3- and 4-positions on the arene ring of the phenylethyl group. In spite of the similarity of the two molecules, there are some notable differences in their conformations. Most importantly, the dihedral angle between the planes of the two six-membered arene rings in (I) is *ca* 106°, while the rings in (III) are nearly parallel (dihedral angle *ca* 2°). This difference is

Figure 2

(a) Molecules of (I) are linked into dimers across centers of inversion by weak amine–nitro $N-H\cdots O$ hydrogen bonds (dashed lines). The view is onto the (010) plane. [Symmetry code: (#) $-x + 1, -y + 1, -z + 1$.] (b) An alternative view of the same set of molecules as in part (a), showing the nonparallel arrangement of the arene rings. Displacement ellipsoids are drawn at the 70% probability level.

Table 2

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

$D-H\cdots A$	$D-H$	$H\cdots A$	$D\cdots A$	$D-H\cdots A$
$N1-H1\cdots O1$	0.844 (18)	2.029 (18)	2.6495 (15)	129.8 (15)
$N1-H1\cdots O1^i$	0.844 (18)	2.822 (18)	3.644 (1)	165.3 (15)

Symmetry code: (i) $-x + 1, -y + 1, -z + 1$.

attributable primarily to the $C1-N1-C7-C8$ torsion angle, which is 177.32 (12)° in (I) and -85.5 (2)° in (III). Other less drastic differences include rotations about the $N1-C1$ [$C7-N1-C1-C6$ torsion angle = -10.9 (2)° in (I) *versus* -0.9 (2)° in (III)] and $C4-N3$ [torsion angle $O3-N3-C4-C3$ = -12.6 (2)° in (I) *versus* -1.2 (2)° in (III)] bonds.

As was the case in (III), neighboring molecules of (I) are related across centers of inversion so as to permit an intermolecular $N-H\cdots O$ hydrogen bond between the amine group on one molecule and the nitro group on the other molecule (Fig. 2a). The amine H1 atom thus participates in a three-center hydrogen bond with two nitro O1 atoms, and each O1 atom serves as an acceptor for both intra- and intermolecular hydrogen bonds (Table 2). The intermolecular $H1\cdots O1^i$ distance of 2.822 (18) Å [symmetry code: (i) $-x + 1, -y + 1, -z + 1$] is significantly longer than the distance of 2.381 (19) Å observed in (III). It is also beyond the typical range for this type of amine–nitro $N-H\cdots O$ interaction (Panunto *et al.*, 1987), making it a weak hydrogen bond at best. The nonparallel intramolecular arrangement of the arene rings and the overall bent shape of the molecules of (I), among other factors, lead to a packing pattern (Fig. 2b) in which π – π stacking interactions appear to be precluded.

Enantiomeric *N*-(4-methylsulfonyl-2-nitrophenyl)-L-phenylalanine, (II), crystallizes in the noncentrosymmetric monoclinic space group $C2$ with one molecule in the asymmetric unit (Fig. 3). The absolute configuration was assigned based on the known configuration of the L-phenylalanine starting material and established through refinement of the Flack parameter (Parsons *et al.*, 2013). As in (I), the amine H atom forms an intramolecular $N-H\cdots O$ hydrogen bond with the adjacent nitro group (Table 3). The C–O bond lengths of the

Figure 3

The molecular structure of (II), showing the atom-labeling scheme and 70% probability displacement ellipsoids for the non-H atoms. The intramolecular hydrogen bond is shown as a dashed line.

carboxylic acid group are consistent with the placement of the acidic H atom on atom O6 [C9—O6 = 1.324 (3) Å] and with atom O5 being part of a free carbonyl group [C9—O5 = 1.191 (3) Å]. L-Phenylalanine (II) differs from 4-methylsulfonyl-2-nitro-*N*-(2-phenylethyl)aniline, (IV) (Wade *et al.*, 2013), only in the presence of the carboxylic acid group on the phenylethyl group.

As was the case with (I), the presence of this one additional group substantially changes the conformation of the molecule. The dihedral angle between the two arene rings is *ca* 62° in (II), but *ca* 107° in (IV). The difference is attributable primarily to the torsion angles C1—N1—C8—C10 [149.3 (2)° in (II) *versus* −175.70 (7)° in (IV)] and N1—C8—C10—C11 [−178.12 (18)° in (II) *versus* −61.20 (8)° in (IV)]. In addition, there are smaller but noticeable differences in the positioning of the nitro [O1—N2—C2—C1 torsion angle −20.2 (3)° in (II) *versus* −4.4 (1)° in (IV)] and methylsulfonyl [C7—S1—C4—

Table 3

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

$D-H\cdots A$	$D-H$	$H\cdots A$	$D\cdots A$	$D-H\cdots A$
O6—H61 $\cdots$ O4 ⁱ	0.83 (4)	1.90 (4)	2.720 (3)	168 (4)
N1—H1 $\cdots$ O1	0.87 (3)	1.98 (4)	2.642 (3)	132 (3)

Symmetry code: (i) $-x + 2, y + 1, -z + 1$.

C5 torsion angle 81.4 (2)° in (II) *versus* 110.98 (6)° in (IV)] groups.

Unlike (I), the molecules of (II) are not joined through intermolecular amine–nitro N—H $\cdots$ O hydrogen bonds. The molecules of (II) are positioned with the amine and nitro groups of adjacent molecules directed towards each other (Fig. 4a), but the closest intermolecular distance, *i.e.* H1 $\cdots$ O2 ($-x + \frac{3}{2}, y + \frac{1}{2}, -z + 1$) of *ca* 3.1 Å, is too great even for a three-center hydrogen bond. Instead, molecules related by twofold rotation along the *b* axis are linked into dimers by two intermolecular O—H $\cdots$ O hydrogen bonds between the carboxylic acid and sulfone groups (Table 3). Similar O—H $\cdots$ O intermolecular interactions between hydroxy and sulfone groups have been observed in 4,4'-sulfonoldiphenol (Glidewell & Ferguson, 1996). These interactions and the chirality of the structure of (II) preclude the familiar inversion-related hydrogen bonding between carboxylic acid groups seen in many classic structures. The overall packing is such that the arene rings form a zigzag pattern (Fig. 4b) that is devoid of π – π interactions between nearby parallel rings.

Recent unpublished work in our laboratory has indicated that molecules with more hydrophilic character have lower NO-release rates in aqueous solution than similar molecules with greater lipophilic character. We believe that molecules with higher HLB (more hydrophilic) form more organized micelles that restrict NO release, while molecules with lower HLB (more lipophilic) form less organized micelles that are less restrictive of NO release (Israelachvili, 2011). The presence of the carboxylic acid group on (II) would give it a greater hydrophilic balance than the previously reported 4-methylsulfonyl-2-nitro-*N*-(2-phenylethyl)aniline (Wade *et al.*, 2013). On this basis, we would expect (II) to show a lower NO-release rate. By contrast, the addition of the two methoxy groups on (I) might be expected to lower the HLB relative to 2,4-dinitro-*N*-(2-phenylethyl)aniline (Wade *et al.*, 2013); the melting point of (I) is 379 K, while that of the parent without the methoxy groups is 425 K, suggesting weaker intermolecular attractions in (I), leading to a higher NO-release rate. Ongoing experiments are underway to test these hypotheses and develop a better understanding of the relationship between structure and NO-release behavior.

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Figure 4

(a) Molecules of (II) are linked into dimers across twofold axes of rotation by carboxylic acid–sulfone O—H $\cdots$ O hydrogen bonds (dashed lines). The view is onto the (010) plane. [Symmetry code: (#) $-x + 2, y + 1, -z + 1$.] (b) An alternative view of the packing showing the zigzag arrangement of the arene rings. Displacement ellipsoids are drawn at the 70% probability level.

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Two *N*-(2-phenylethyl)nitroaniline derivatives as precursors for slow and sustained nitric oxide release agents

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Computing details

For both compounds, data collection: *CrystalClear*-SM Expert (Rigaku, 2011); cell refinement: *CrystalClear*-SM Expert (Rigaku, 2011); data reduction: *CrystalClear*-SM Expert (Rigaku, 2011); program(s) used to solve structure: *SHELXS97* (Sheldrick, 2008); program(s) used to refine structure: *SHELXL97* (Sheldrick, 2008); molecular graphics: *CrystalMaker* (Palmer, 2013); software used to prepare material for publication: *CrystalStructure* (Rigaku, 2010).

(C₁₆H₁₇N₃O₆) *N*-[2-(3,4-Dimethoxyphenyl)ethyl]-2,4-dinitroaniline

Crystal data

C ₁₆ H ₁₇ N ₃ O ₆	$F(000) = 728.00$
$M_r = 347.33$	$D_x = 1.475 \text{ Mg m}^{-3}$
Monoclinic, $P2_1/c$	Melting point: 379 K
Hall symbol: -P 2ybc	Mo $K\alpha$ radiation, $\lambda = 0.71075 \text{ \AA}$
$a = 13.0087 (12) \text{ \AA}$	Cell parameters from 13648 reflections
$b = 7.2092 (6) \text{ \AA}$	$\theta = 3.1\text{--}27.6^\circ$
$c = 17.0024 (16) \text{ \AA}$	$\mu = 0.12 \text{ mm}^{-1}$
$\beta = 101.297 (7)^\circ$	$T = 173 \text{ K}$
$V = 1563.6 (3) \text{ \AA}^3$	Prism, yellow
$Z = 4$	$0.30 \times 0.23 \times 0.11 \text{ mm}$

Data collection

Rigaku XtaLAB mini	3578 independent reflections
diffractometer	2913 reflections with $F^2 > 2.0\sigma(F^2)$
Detector resolution: $6.827 \text{ pixels mm}^{-1}$	$R_{\text{int}} = 0.030$
ω scans	$\theta_{\text{max}} = 27.5^\circ$
Absorption correction: multi-scan	$h = 0 \rightarrow 16$
(<i>REQAB</i> ; Rigaku, 1998)	$k = 0 \rightarrow 9$
$T_{\text{min}} = 0.828$, $T_{\text{max}} = 0.987$	$l = -22 \rightarrow 21$
16236 measured reflections	

Refinement

Refinement on F^2	Secondary atom site location: difference Fourier map
$R[F^2 > 2\sigma(F^2)] = 0.039$	Hydrogen site location: inferred from neighbouring sites
$wR(F^2) = 0.102$	H atoms treated by a mixture of independent and constrained refinement
$S = 1.03$	$w = 1/[\sigma^2(F_o^2) + (0.0463P)^2 + 0.5551P]$
3578 reflections	where $P = (F_o^2 + 2F_c^2)/3$
232 parameters	$(\Delta/\sigma)_{\text{max}} < 0.001$
0 restraints	
Primary atom site location: structure-invariant direct methods	

$$\Delta\rho_{\max} = 0.25 \text{ e } \text{\AA}^{-3}$$

$$\Delta\rho_{\min} = -0.21 \text{ e } \text{\AA}^{-3}$$

Special details

Geometry. ENTER SPECIAL DETAILS OF THE MOLECULAR GEOMETRY

Refinement. Refinement was performed using all reflections. The weighted R-factor (wR) and goodness of fit (S) are based on F^2 . R-factor (gt) are based on F. The threshold expression of $F^2 > 2.0 \text{ sigma}(F^2)$ is used only for calculating R-factor (gt).

Fractional atomic coordinates and isotropic or equivalent isotropic displacement parameters ($\text{\AA}^2$)

	x	y	z	$U_{\text{iso}}^*/U_{\text{eq}}$
O1	0.50724 (8)	0.36301 (14)	0.55427 (6)	0.0306 (3)
O2	0.59579 (8)	0.20106 (16)	0.65080 (6)	0.0376 (3)
O3	0.50832 (10)	−0.40323 (16)	0.70903 (7)	0.0420 (3)
O4	0.35411 (10)	−0.51340 (17)	0.66066 (8)	0.0517 (4)
O5	−0.11203 (7)	0.32905 (14)	0.18040 (5)	0.0258 (3)
O6	−0.03845 (8)	0.26591 (16)	0.05233 (6)	0.0334 (3)
N1	0.33525 (9)	0.22648 (17)	0.46307 (7)	0.0269 (3)
N2	0.52004 (8)	0.22122 (16)	0.59592 (6)	0.0235 (3)
N3	0.42160 (10)	−0.39309 (17)	0.66489 (8)	0.0331 (3)
C1	0.35750 (10)	0.08081 (19)	0.51259 (8)	0.0228 (3)
C2	0.44436 (10)	0.07215 (18)	0.57820 (8)	0.0217 (3)
C3	0.46459 (10)	−0.08259 (19)	0.62744 (8)	0.0240 (3)
C4	0.39807 (11)	−0.23130 (19)	0.61328 (8)	0.0265 (3)
C5	0.31178 (11)	−0.2314 (2)	0.55030 (9)	0.0308 (4)
C6	0.29284 (11)	−0.0811 (2)	0.50082 (9)	0.0284 (3)
C7	0.25803 (11)	0.2181 (2)	0.38831 (8)	0.0282 (3)
C8	0.24450 (11)	0.4040 (2)	0.34585 (9)	0.0288 (3)
C9	0.17168 (10)	0.37890 (18)	0.26557 (8)	0.0243 (3)
C10	0.06282 (10)	0.37334 (18)	0.26141 (8)	0.0224 (3)
C11	−0.00532 (10)	0.33682 (18)	0.18985 (8)	0.0215 (3)
C12	0.03522 (11)	0.30424 (19)	0.12024 (8)	0.0243 (3)
C13	0.14211 (11)	0.3120 (2)	0.12406 (8)	0.0287 (3)
C14	0.21010 (11)	0.3498 (2)	0.19655 (9)	0.0285 (3)
C15	−0.15456 (11)	0.3490 (2)	0.25142 (8)	0.0275 (3)
C16	−0.00099 (14)	0.2459 (3)	−0.02060 (9)	0.0421 (4)
H1	0.3796 (14)	0.313 (3)	0.4672 (10)	0.034 (5)*
H3	0.5237	−0.0852	0.6703	0.0288*
H5	0.2663	−0.3356	0.5418	0.0369*
H6	0.2348	−0.0841	0.4571	0.0340*
H7A	0.1898	0.1779	0.4000	0.0339*
H7B	0.2804	0.1246	0.3525	0.0339*
H8A	0.2146	0.4953	0.3786	0.0346*
H8B	0.3133	0.4508	0.3380	0.0346*
H10	0.0356	0.3950	0.3085	0.0269*
H13	0.1696	0.2914	0.0770	0.0345*
H14	0.2835	0.3556	0.1983	0.0342*
H15A	−0.2310	0.3357	0.2379	0.0330*

H15B	−0.1367	0.4718	0.2748	0.0330*
H15C	−0.1252	0.2532	0.2903	0.0330*
H16A	0.0481	0.1415	−0.0158	0.0505*
H16B	0.0349	0.3599	−0.0313	0.0505*
H16C	−0.0602	0.2226	−0.0648	0.0505*

Atomic displacement parameters (Å²)

	U^{11}	U^{22}	U^{33}	U^{12}	U^{13}	U^{23}
O1	0.0342 (6)	0.0262 (6)	0.0283 (5)	−0.0051 (5)	−0.0016 (5)	0.0046 (4)
O2	0.0286 (6)	0.0401 (7)	0.0363 (6)	−0.0076 (5)	−0.0125 (5)	0.0083 (5)
O3	0.0509 (7)	0.0392 (7)	0.0350 (6)	0.0064 (6)	0.0061 (6)	0.0117 (5)
O4	0.0535 (8)	0.0356 (7)	0.0713 (9)	−0.0086 (6)	0.0254 (7)	0.0133 (7)
O5	0.0189 (5)	0.0352 (6)	0.0215 (5)	0.0017 (4)	−0.0004 (4)	−0.0005 (4)
O6	0.0329 (6)	0.0477 (7)	0.0178 (5)	0.0003 (5)	0.0007 (4)	−0.0013 (5)
N1	0.0223 (6)	0.0273 (7)	0.0277 (6)	−0.0026 (5)	−0.0037 (5)	0.0001 (5)
N2	0.0212 (6)	0.0261 (6)	0.0217 (6)	−0.0013 (5)	0.0006 (5)	0.0002 (5)
N3	0.0419 (8)	0.0260 (7)	0.0356 (7)	0.0003 (6)	0.0179 (6)	0.0039 (6)
C1	0.0189 (6)	0.0258 (7)	0.0236 (6)	0.0024 (5)	0.0037 (5)	−0.0035 (6)
C2	0.0193 (6)	0.0240 (7)	0.0218 (6)	−0.0008 (5)	0.0042 (5)	−0.0031 (5)
C3	0.0248 (7)	0.0276 (7)	0.0205 (6)	0.0021 (6)	0.0067 (5)	−0.0020 (6)
C4	0.0307 (7)	0.0243 (7)	0.0269 (7)	0.0016 (6)	0.0114 (6)	0.0016 (6)
C5	0.0279 (8)	0.0277 (8)	0.0384 (8)	−0.0052 (6)	0.0107 (6)	−0.0041 (6)
C6	0.0212 (7)	0.0315 (8)	0.0306 (7)	−0.0017 (6)	0.0008 (6)	−0.0040 (6)
C7	0.0234 (7)	0.0283 (7)	0.0287 (7)	−0.0004 (6)	−0.0054 (6)	−0.0003 (6)
C8	0.0227 (7)	0.0270 (8)	0.0326 (8)	−0.0015 (6)	−0.0051 (6)	0.0012 (6)
C9	0.0226 (7)	0.0186 (6)	0.0290 (7)	0.0000 (5)	−0.0016 (6)	0.0041 (6)
C10	0.0233 (7)	0.0211 (7)	0.0218 (6)	0.0016 (5)	0.0018 (5)	0.0012 (5)
C11	0.0206 (7)	0.0195 (6)	0.0230 (7)	0.0020 (5)	0.0013 (5)	0.0034 (5)
C12	0.0268 (7)	0.0236 (7)	0.0208 (6)	0.0027 (6)	0.0003 (5)	0.0041 (6)
C13	0.0308 (8)	0.0302 (8)	0.0268 (7)	0.0026 (6)	0.0097 (6)	0.0051 (6)
C14	0.0205 (7)	0.0278 (8)	0.0368 (8)	0.0008 (6)	0.0045 (6)	0.0061 (6)
C15	0.0231 (7)	0.0331 (8)	0.0265 (7)	0.0012 (6)	0.0053 (6)	−0.0029 (6)
C16	0.0505 (10)	0.0546 (11)	0.0210 (7)	0.0033 (8)	0.0068 (7)	−0.0018 (7)

Geometric parameters (Å, °)

O4—N3	1.2262 (18)	C14—C13	1.3959 (19)
O3—N3	1.2286 (17)	C13—C12	1.380 (2)
O2—N2	1.2258 (14)	C12—C11	1.407 (2)
O1—N2	1.2361 (15)	C11—C10	1.3831 (18)
O6—C12	1.3764 (16)	N1—H1	0.844 (18)
O6—C16	1.426 (2)	C3—H3	0.950
O5—C11	1.3670 (16)	C6—H6	0.950
O5—C15	1.4306 (18)	C5—H5	0.950
N3—C4	1.4556 (19)	C7—H7A	0.990
N2—C2	1.4487 (17)	C7—H7B	0.990
N1—C1	1.3417 (18)	C8—H8A	0.990

N1—C7	1.4588 (17)	C8—H8B	0.990
C4—C3	1.369 (2)	C14—H14	0.950
C4—C5	1.3913 (19)	C13—H13	0.950
C3—C2	1.3886 (19)	C10—H10	0.950
C2—C1	1.4252 (17)	C15—H15A	0.980
C1—C6	1.430 (2)	C15—H15B	0.980
C5—C6	1.364 (2)	C15—H15C	0.980
C7—C8	1.516 (2)	C16—H16A	0.980
C8—C9	1.5122 (19)	C16—H16B	0.980
C9—C14	1.379 (3)	C16—H16C	0.980
C9—C10	1.4046 (19)		
C12—O6—C16	116.71 (12)	C7—N1—H1	116.5 (11)
C11—O5—C15	116.64 (10)	C4—C3—H3	120.512
O4—N3—O3	123.71 (13)	C2—C3—H3	120.513
O4—N3—C4	117.89 (12)	C1—C6—H6	118.934
O3—N3—C4	118.38 (13)	C5—C6—H6	118.938
O2—N2—O1	122.15 (12)	C4—C5—H5	120.152
O2—N2—C2	118.85 (11)	C6—C5—H5	120.153
O1—N2—C2	118.98 (10)	N1—C7—H7A	109.218
C1—N1—C7	122.78 (12)	N1—C7—H7B	109.214
N3—C4—C3	118.06 (12)	C8—C7—H7A	109.220
N3—C4—C5	120.42 (13)	C8—C7—H7B	109.228
C3—C4—C5	121.50 (13)	H7A—C7—H7B	107.910
C4—C3—C2	118.98 (12)	C7—C8—H8A	109.992
N2—C2—C3	115.45 (11)	C7—C8—H8B	109.991
N2—C2—C1	122.18 (12)	C9—C8—H8A	109.984
C3—C2—C1	122.32 (12)	C9—C8—H8B	109.977
N1—C1—C2	124.47 (12)	H8A—C8—H8B	108.366
N1—C1—C6	120.17 (12)	C9—C14—H14	119.710
C2—C1—C6	115.36 (12)	C13—C14—H14	119.718
C1—C6—C5	122.13 (13)	C14—C13—H13	119.748
C4—C5—C6	119.69 (14)	C12—C13—H13	119.746
N1—C7—C8	111.96 (12)	C9—C10—H10	119.473
C7—C8—C9	108.53 (11)	C11—C10—H10	119.473
C8—C9—C14	121.27 (13)	O6—C16—H16A	109.482
C8—C9—C10	119.74 (13)	O6—C16—H16B	109.472
C14—C9—C10	118.87 (12)	O6—C16—H16C	109.471
C9—C14—C13	120.57 (14)	H16A—C16—H16B	109.469
C14—C13—C12	120.51 (14)	H16A—C16—H16C	109.468
O6—C12—C13	125.24 (14)	H16B—C16—H16C	109.464
O6—C12—C11	115.16 (13)	O5—C15—H15A	109.479
C13—C12—C11	119.60 (12)	O5—C15—H15B	109.477
O5—C11—C12	115.71 (11)	O5—C15—H15C	109.466
O5—C11—C10	124.91 (13)	H15A—C15—H15B	109.476
C12—C11—C10	119.38 (13)	H15A—C15—H15C	109.468
C9—C10—C11	121.05 (14)	H15B—C15—H15C	109.462
C1—N1—H1	117.9 (11)		

C16—O6—C12—C13	−4.7 (2)	N2—C2—C1—C6	177.12 (11)
C16—O6—C12—C11	175.43 (12)	C3—C2—C1—N1	−179.48 (13)
C15—O5—C11—C12	175.81 (10)	C3—C2—C1—C6	−0.2 (2)
C15—O5—C11—C10	−4.10 (18)	N1—C1—C6—C5	−179.15 (13)
O4—N3—C4—C3	168.68 (13)	C2—C1—C6—C5	1.5 (2)
O4—N3—C4—C5	−13.0 (2)	C1—C6—C5—C4	−1.7 (3)
O3—N3—C4—C3	−12.6 (2)	N1—C7—C8—C9	174.50 (11)
O3—N3—C4—C5	165.72 (13)	C7—C8—C9—C14	−95.55 (15)
O2—N2—C2—C3	1.08 (18)	C7—C8—C9—C10	80.42 (15)
O2—N2—C2—C1	−176.42 (11)	C8—C9—C14—C13	174.79 (11)
O1—N2—C2—C3	179.69 (11)	C8—C9—C10—C11	−175.15 (11)
O1—N2—C2—C1	2.20 (19)	C14—C9—C10—C11	0.92 (19)
C1—N1—C7—C8	177.32 (12)	C10—C9—C14—C13	−1.2 (2)
C7—N1—C1—C2	168.31 (12)	C9—C14—C13—C12	0.4 (2)
C7—N1—C1—C6	−10.9 (2)	C14—C13—C12—O6	−179.16 (12)
N3—C4—C3—C2	179.12 (12)	C14—C13—C12—C11	0.7 (2)
N3—C4—C5—C6	−177.78 (13)	O6—C12—C11—O5	−1.03 (17)
C3—C4—C5—C6	0.5 (3)	O6—C12—C11—C10	178.89 (11)
C5—C4—C3—C2	0.8 (3)	C13—C12—C11—O5	179.09 (12)
C4—C3—C2—N2	−178.41 (12)	C13—C12—C11—C10	−1.00 (19)
C4—C3—C2—C1	−0.9 (2)	O5—C11—C10—C9	−179.91 (11)
N2—C2—C1—N1	−2.2 (3)	C12—C11—C10—C9	0.18 (19)

Hydrogen-bond geometry (Å, °)

<i>D</i> —H $\cdots$ <i>A</i>	<i>D</i> —H	H $\cdots$ <i>A</i>	<i>D</i> $\cdots$ <i>A</i>	<i>D</i> —H $\cdots$ <i>A</i>
N1—H1 $\cdots$ O1	0.844 (18)	2.029 (18)	2.6495 (15)	129.8 (15)
N1—H1 $\cdots$ O1 ⁱ	0.844 (18)	2.822 (18)	3.644 (1)	165.3 (15)

Symmetry code: (i) $-x+1, -y+1, -z+1$.

(C₁₆H₁₆N₂O₆S) *N*-(4-Methylsulfonyl-2-nitrophenyl)-*L*-phenylalanine

Crystal data

C₁₆H₁₆N₂O₆S

M_r = 364.38

Monoclinic, *C*2_y

Hall symbol: *C* 2_y

a = 21.260 (3) Å

b = 5.7264 (6) Å

c = 14.2762 (16) Å

β = 103.456 (7)°

V = 1690.3 (4) Å³

Z = 4

F(000) = 760.00

D_x = 1.428 Mg m^{−3}

Melting point: 443 K

Mo *K* α radiation, λ = 0.71075 Å

Cell parameters from 9423 reflections

θ = 3.1–30.2°

μ = 0.23 mm^{−1}

T = 173 K

Blade, yellow

0.80 × 0.14 × 0.04 mm

Data collection

Rigaku XtaLAB mini

diffractometer

Radiation source: fine focus sealed tube

Detector resolution: 6.827 pixels mm^{−1}

ω scans

Absorption correction: multi-scan

(*REQAB*; Rigaku, 1998)

*T*_{min} = 0.815, *T*_{max} = 0.991

10478 measured reflections
 4851 independent reflections
 4201 reflections with $I > 2\sigma(I)$
 $R_{\text{int}} = 0.029$

$\theta_{\text{max}} = 30.0^\circ$, $\theta_{\text{min}} = 3.1^\circ$
 $h = -29 \rightarrow 29$
 $k = -8 \rightarrow 8$
 $l = -20 \rightarrow 20$

Refinement

Refinement on F^2
 $R[F^2 > 2\sigma(F^2)] = 0.039$
 $wR(F^2) = 0.092$
 $S = 1.03$
 4851 reflections
 235 parameters
 1 restraint
 Primary atom site location: structure-invariant
 direct methods
 Secondary atom site location: difference Fourier
 map

Hydrogen site location: inferred from
 neighbouring sites
 H atoms treated by a mixture of independent
 and constrained refinement
 $w = 1/[\sigma^2(F_o^2) + (0.0425P)^2 + 0.4064P]$
 where $P = (F_o^2 + 2F_c^2)/3$
 $(\Delta/\sigma)_{\text{max}} = 0.001$
 $\Delta\rho_{\text{max}} = 0.30 \text{ e } \text{\AA}^{-3}$
 $\Delta\rho_{\text{min}} = -0.29 \text{ e } \text{\AA}^{-3}$
 Absolute structure: Flack x determined using
 1620 quotients $[(I^+)-(I^-)]/[(I^+)+(I^-)]$ (Parsons *et al.*, 2013)
 Absolute structure parameter: 0.01 (4)

Special details

Geometry. ENTER SPECIAL DETAILS OF THE MOLECULAR GEOMETRY

Refinement. Refinement was performed using all reflections. The weighted R-factor (wR) and goodness of fit (S) are based on F^2 . R-factor (gt) are based on F. The threshold expression of $F^2 > 2.0 \text{ sigma}(F^2)$ is used only for calculating R-factor (gt).

Fractional atomic coordinates and isotropic or equivalent isotropic displacement parameters ($\text{\AA}^2$)

	<i>x</i>	<i>y</i>	<i>z</i>	$U_{\text{iso}}^*/U_{\text{eq}}$
S1	0.92742 (3)	0.54808 (11)	0.78047 (4)	0.03167 (15)
O1	0.78519 (8)	1.3718 (4)	0.54188 (12)	0.0359 (4)
O2	0.75778 (10)	1.1853 (5)	0.65814 (15)	0.0512 (6)
O3	0.88106 (10)	0.5710 (5)	0.83856 (14)	0.0491 (6)
O4	0.94245 (9)	0.3156 (4)	0.75374 (14)	0.0391 (5)
O5	0.93194 (10)	1.4082 (4)	0.35172 (17)	0.0527 (6)
O6	0.96349 (9)	1.0683 (4)	0.30252 (14)	0.0378 (5)
N1	0.84399 (10)	1.1274 (4)	0.43040 (13)	0.0287 (5)
N2	0.79068 (9)	1.2052 (4)	0.59793 (14)	0.0305 (5)
C1	0.86254 (10)	0.9947 (4)	0.50992 (15)	0.0248 (5)
C2	0.83769 (10)	1.0258 (5)	0.59353 (14)	0.0255 (5)
C3	0.85673 (11)	0.8860 (5)	0.67428 (15)	0.0269 (5)
C4	0.90084 (11)	0.7118 (5)	0.67551 (16)	0.0280 (5)
C5	0.92597 (11)	0.6716 (5)	0.59408 (17)	0.0307 (5)
C6	0.90701 (11)	0.8090 (5)	0.51391 (16)	0.0296 (5)
C7	1.00056 (16)	0.6784 (7)	0.8408 (2)	0.0517 (8)
C8	0.86037 (10)	1.0792 (5)	0.33917 (14)	0.0259 (5)
C9	0.92279 (11)	1.2061 (5)	0.33397 (16)	0.0299 (5)
C10	0.80554 (11)	1.1692 (5)	0.25657 (17)	0.0325 (6)
C11	0.81931 (11)	1.1159 (5)	0.15974 (16)	0.0298 (5)
C12	0.80202 (14)	0.9045 (6)	0.11519 (19)	0.0414 (7)
C13	0.81573 (17)	0.8542 (6)	0.0269 (2)	0.0536 (9)

C14	0.84734 (16)	1.0163 (7)	−0.01718 (19)	0.0528 (8)
C15	0.86431 (15)	1.2275 (7)	0.0258 (2)	0.0483 (8)
C16	0.85063 (14)	1.2780 (5)	0.11417 (18)	0.0365 (6)
H1	0.8200 (15)	1.248 (6)	0.435 (3)	0.036 (8)*
H3	0.8391	0.9112	0.7288	0.0323*
H5	0.9561	0.5489	0.5947	0.0368*
H6	0.9242	0.7788	0.4594	0.0355*
H61	0.9935 (18)	1.151 (7)	0.294 (3)	0.053 (11)*
H7A	0.9924	0.8396	0.8578	0.0620*
H7B	1.0310	0.6782	0.7987	0.0620*
H7C	1.0191	0.5901	0.8995	0.0620*
H8	0.8660	0.9072	0.3320	0.0310*
H10A	0.7643	1.0948	0.2608	0.0389*
H10B	0.8009	1.3401	0.2632	0.0389*
H12	0.7804	0.7918	0.1452	0.0497*
H13	0.8034	0.7080	−0.0032	0.0643*
H14	0.8572	0.9811	−0.0772	0.0634*
H15	0.8855	1.3401	−0.0048	0.0580*
H16	0.8628	1.4249	0.1437	0.0438*

Atomic displacement parameters (Å²)

	U^{11}	U^{22}	U^{33}	U^{12}	U^{13}	U^{23}
S1	0.0401 (3)	0.0313 (3)	0.0267 (3)	0.0028 (3)	0.0140 (2)	0.0060 (3)
O1	0.0402 (10)	0.0352 (11)	0.0334 (9)	0.0080 (8)	0.0112 (8)	0.0037 (8)
O2	0.0602 (13)	0.0562 (15)	0.0498 (12)	0.0232 (11)	0.0380 (10)	0.0124 (11)
O3	0.0652 (13)	0.0524 (14)	0.0400 (10)	0.0162 (12)	0.0330 (9)	0.0151 (11)
O4	0.0469 (11)	0.0327 (11)	0.0434 (10)	0.0028 (9)	0.0223 (9)	0.0046 (9)
O5	0.0466 (12)	0.0436 (13)	0.0776 (16)	−0.0149 (10)	0.0339 (11)	−0.0275 (12)
O6	0.0339 (9)	0.0347 (11)	0.0502 (10)	0.0036 (9)	0.0209 (8)	0.0006 (10)
N1	0.0315 (10)	0.0345 (12)	0.0222 (9)	0.0049 (9)	0.0109 (8)	0.0009 (8)
N2	0.0320 (10)	0.0347 (12)	0.0264 (10)	0.0040 (9)	0.0103 (8)	−0.0026 (9)
C1	0.0231 (10)	0.0300 (14)	0.0221 (10)	−0.0025 (9)	0.0068 (8)	−0.0024 (9)
C2	0.0248 (10)	0.0297 (12)	0.0234 (9)	0.0009 (10)	0.0085 (8)	−0.0022 (10)
C3	0.0286 (11)	0.0316 (13)	0.0229 (10)	−0.0008 (10)	0.0104 (9)	−0.0028 (10)
C4	0.0304 (11)	0.0322 (13)	0.0230 (10)	0.0000 (10)	0.0092 (9)	0.0017 (10)
C5	0.0310 (12)	0.0356 (15)	0.0278 (11)	0.0058 (10)	0.0114 (9)	0.0004 (11)
C6	0.0295 (11)	0.0390 (14)	0.0229 (10)	0.0039 (10)	0.0111 (9)	0.0007 (10)
C7	0.0612 (19)	0.050 (2)	0.0350 (14)	−0.0043 (16)	−0.0064 (13)	0.0109 (14)
C8	0.0296 (10)	0.0292 (14)	0.0202 (9)	−0.0006 (10)	0.0086 (8)	−0.0006 (9)
C9	0.0313 (12)	0.0357 (14)	0.0247 (11)	−0.0010 (11)	0.0104 (9)	−0.0043 (10)
C10	0.0312 (12)	0.0392 (15)	0.0268 (11)	0.0004 (11)	0.0064 (9)	0.0050 (11)
C11	0.0338 (12)	0.0310 (14)	0.0223 (10)	0.0004 (10)	0.0017 (9)	0.0032 (9)
C12	0.0530 (16)	0.0331 (15)	0.0331 (13)	−0.0051 (13)	−0.0006 (12)	0.0026 (11)
C13	0.079 (3)	0.0386 (18)	0.0330 (14)	0.0070 (17)	−0.0074 (14)	−0.0092 (13)
C14	0.0698 (19)	0.063 (3)	0.0234 (12)	0.0159 (18)	0.0067 (12)	−0.0060 (14)
C15	0.0620 (19)	0.057 (2)	0.0280 (13)	0.0010 (16)	0.0145 (13)	0.0061 (13)
C16	0.0527 (16)	0.0325 (15)	0.0242 (11)	−0.0031 (12)	0.0089 (11)	0.0013 (10)

Geometric parameters (Å, °)

S1—O3	1.434 (2)	C11—C16	1.389 (3)
S1—O4	1.441 (2)	C12—C13	1.388 (4)
S1—C7	1.759 (3)	C13—C14	1.381 (5)
S1—C4	1.746 (2)	C14—C15	1.366 (5)
O2—N2	1.233 (3)	C15—C16	1.390 (4)
O1—N2	1.233 (3)	O6—H61	0.83 (4)
O5—C9	1.191 (3)	N1—H1	0.87 (3)
O6—C9	1.324 (3)	C7—H7A	0.980
N2—C2	1.445 (3)	C7—H7B	0.980
N1—C1	1.346 (3)	C7—H7C	0.980
N1—C8	1.451 (3)	C5—H5	0.950
C4—C5	1.407 (3)	C6—H6	0.950
C4—C3	1.367 (3)	C3—H3	0.950
C5—C6	1.370 (3)	C8—H8	1.000
C6—C1	1.415 (3)	C10—H10A	0.990
C1—C2	1.424 (3)	C10—H10B	0.990
C2—C3	1.384 (3)	C12—H12	0.950
C8—C9	1.530 (3)	C13—H13	0.950
C8—C10	1.541 (3)	C14—H14	0.950
C10—C11	1.509 (3)	C15—H15	0.950
C11—C12	1.377 (4)	C16—H16	0.950
O3—S1—O4	117.54 (13)	C14—C15—C16	120.2 (4)
O3—S1—C7	109.04 (15)	C11—C16—C15	120.7 (3)
O3—S1—C4	108.56 (12)	C9—O6—H61	107 (3)
O4—S1—C7	107.24 (16)	C1—N1—H1	117 (2)
O4—S1—C4	108.43 (12)	C8—N1—H1	119 (2)
C7—S1—C4	105.36 (13)	S1—C7—H7A	109.477
O2—N2—O1	122.7 (3)	S1—C7—H7B	109.475
O2—N2—C2	118.4 (3)	S1—C7—H7C	109.473
O1—N2—C2	118.9 (2)	H7A—C7—H7B	109.471
C1—N1—C8	124.4 (3)	H7A—C7—H7C	109.464
S1—C4—C5	120.8 (2)	H7B—C7—H7C	109.466
S1—C4—C3	119.15 (19)	C4—C5—H5	119.936
C5—C4—C3	120.0 (3)	C6—C5—H5	119.943
C4—C5—C6	120.1 (3)	C5—C6—H6	119.025
C5—C6—C1	122.0 (3)	C1—C6—H6	119.023
N1—C1—C6	121.3 (3)	C4—C3—H3	120.015
N1—C1—C2	122.9 (3)	C2—C3—H3	120.011
C6—C1—C2	115.8 (2)	N1—C8—H8	109.758
N2—C2—C1	121.4 (2)	C9—C8—H8	109.750
N2—C2—C3	116.5 (2)	C10—C8—H8	109.747
C1—C2—C3	122.1 (3)	C8—C10—H10A	109.420
C4—C3—C2	120.0 (3)	C8—C10—H10B	109.411
N1—C8—C9	110.20 (18)	C11—C10—H10A	109.422
N1—C8—C10	109.05 (19)	C11—C10—H10B	109.413

C9—C8—C10	108.3 (2)	H10A—C10—H10B	108.036
O5—C9—O6	124.3 (3)	C11—C12—H12	119.607
O5—C9—C8	123.5 (3)	C13—C12—H12	119.609
O6—C9—C8	112.1 (3)	C12—C13—H13	119.945
C8—C10—C11	111.1 (2)	C14—C13—H13	119.927
C10—C11—C12	120.9 (3)	C13—C14—H14	120.141
C10—C11—C16	120.7 (3)	C15—C14—H14	120.129
C12—C11—C16	118.5 (3)	C14—C15—H15	119.912
C11—C12—C13	120.8 (3)	C16—C15—H15	119.899
C12—C13—C14	120.1 (3)	C11—C16—H16	119.643
C13—C14—C15	119.7 (3)	C15—C16—H16	119.655
O3—S1—C4—C5	−161.93 (17)	N1—C1—C2—C3	179.22 (19)
O3—S1—C4—C3	20.3 (3)	C6—C1—C2—N2	−178.42 (18)
O4—S1—C4—C5	−33.2 (2)	C6—C1—C2—C3	1.2 (3)
O4—S1—C4—C3	149.08 (17)	N2—C2—C3—C4	179.73 (18)
C7—S1—C4—C5	81.4 (2)	C1—C2—C3—C4	0.1 (4)
C7—S1—C4—C3	−96.4 (2)	N1—C8—C9—O5	−49.8 (3)
O2—N2—C2—C1	160.08 (19)	N1—C8—C9—O6	133.64 (19)
O2—N2—C2—C3	−19.5 (3)	N1—C8—C10—C11	−178.12 (18)
O1—N2—C2—C1	−20.2 (3)	C9—C8—C10—C11	61.9 (3)
O1—N2—C2—C3	160.22 (18)	C10—C8—C9—O5	69.4 (3)
C1—N1—C8—C9	−92.0 (3)	C10—C8—C9—O6	−107.1 (2)
C1—N1—C8—C10	149.3 (2)	C8—C10—C11—C12	86.3 (3)
C8—N1—C1—C6	7.9 (4)	C8—C10—C11—C16	−92.8 (3)
C8—N1—C1—C2	−170.10 (18)	C10—C11—C12—C13	−178.9 (2)
S1—C4—C5—C6	−176.78 (15)	C10—C11—C16—C15	178.89 (19)
S1—C4—C3—C2	176.55 (15)	C12—C11—C16—C15	−0.2 (4)
C5—C4—C3—C2	−1.2 (4)	C16—C11—C12—C13	0.2 (4)
C3—C4—C5—C6	0.9 (4)	C11—C12—C13—C14	0.3 (5)
C4—C5—C6—C1	0.4 (4)	C12—C13—C14—C15	−0.9 (5)
C5—C6—C1—N1	−179.5 (2)	C13—C14—C15—C16	0.9 (5)
C5—C6—C1—C2	−1.4 (4)	C14—C15—C16—C11	−0.4 (5)
N1—C1—C2—N2	−0.4 (4)		

Hydrogen-bond geometry (Å, °)

<i>D</i> —H $\cdots$ <i>A</i>	<i>D</i> —H	H $\cdots$ <i>A</i>	<i>D</i> $\cdots$ <i>A</i>	<i>D</i> —H $\cdots$ <i>A</i>
O6—H61 $\cdots$ O4 ⁱ	0.83 (4)	1.90 (4)	2.720 (3)	168 (4)
N1—H1 $\cdots$ O1	0.87 (3)	1.98 (4)	2.642 (3)	132 (3)

Symmetry code: (i) $-x+2, y+1, -z+1$.