

Crystal structure of 6-azido-6-deoxy-1,2-O-isopropylidene- α -D-glucofuranoseAdam Wood,^{a,b} Paul V. Bernhardt,^c Ian van Almena^a and Michela I. Simone^{a,b*}

^aDiscipline of Chemistry, University of Newcastle, Callaghan, NSW 2308, Australia, ^bPriority Research Centre for Drug Development, University of Newcastle, Callaghan, NSW 2308, Australia, and ^cSchool of Chemistry and Molecular Biosciences, University of Queensland, Brisbane 4072, Australia. *Correspondence e-mail: michela_simone@yahoo.co.uk

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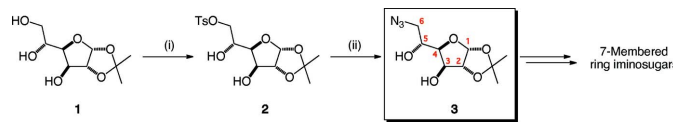
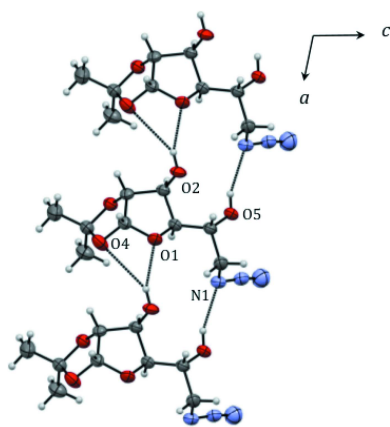
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Short syntheses to high F_{sp^3} index natural-product analogues such as iminosugars are of paramount importance in the investigation of their biological activities and reducing the use of protecting groups is an advantageous synthetic strategy. An isopropylidene group was employed towards the synthesis of seven-membered ring iminosugars and the title compound, $C_9H_{15}N_3O_5$, was crystallized as an intermediate, in which the THF ring is twisted and the dioxolane ring adopts an envelope conformation: the dihedral angle between the rings is $67.50(13)^\circ$. In the crystal, the hydroxyl groups participate in $O-H \cdots(O,O)$ and $O-H \cdots N$ hydrogen-bonding interactions, which generate chains of molecules propagating parallel to the a -axis direction. There is a notable non-classical $C-H \cdots O$ hydrogen bond, which cross-links the [100] chains into (001) sheets.

1. Chemical context

The installation of various functionalities *via* N - and/or O -alkylation has been shown to impart improved biological profiles and potencies to iminosugars (Šesták *et al.*, 2018; Prichard *et al.*, 2018; Simone *et al.*, 2012; Sayce *et al.*, 2016; Woodhouse *et al.*, 2008; Johnson & Houston, 2002). Diminishing the number of synthetic steps to the iminosugar building blocks that are precursors to their alkylated congeners is advantageous. Many iminosugar syntheses start from monosaccharide starting materials (Wood *et al.*, 2018; Lee *et al.*, 2012; Rasmussen & Jensen, 2011). Reducing the number of protecting groups and removing the need for purification by chromatography are useful strategies to a more expedited synthesis of analogues (Katritzky *et al.*, 1991; Steiner *et al.*, 2009; Liu *et al.*, 2014).



Scheme 1. Reaction conditions: (i) tosyl chloride, pyridine, DCM, 32%; (ii) NaN_3 , DMF, 358K, 42 h, 29%. The red atom numbering refers to IUPAC nomenclature for carbohydrates.

In the present study, the only protecting group that was used to synthesize seven-membered ring iminosugars was an isopropylidene group (acetone) to make intermediate **1** from D-glucose. Selective tosylation of the primary hydroxyl group, followed by nucleophilic displacement with sodium azide afforded the title compound **3**, $C_9H_{15}N_3O_5$ (Tsuchiya *et al.*, 1981; Fleet *et al.*, 1989), see Scheme 1.

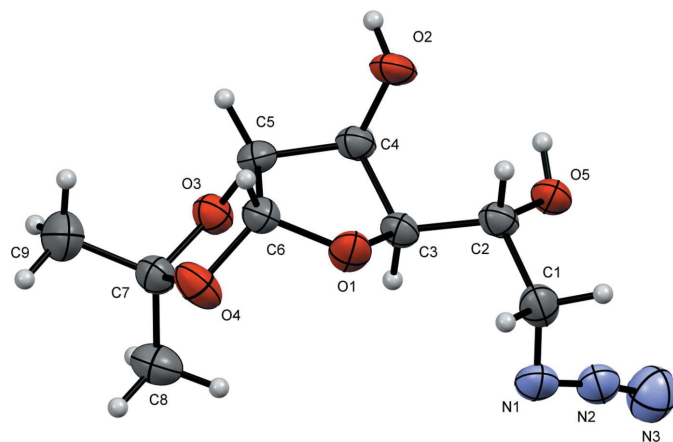


Figure 1
The molecular structure of **3** showing 50% displacement ellipsoids.

Primary alcohols can be tosylated regioselectively over secondary alcohols (Johnson *et al.*, 1963). There are examples of monotosylation of monosaccharides and analogues using di-*n*-butyltin oxide and dimethylaminopyridine as catalyst (Tsuda *et al.*, 1991) and of cyclodextrins (Yamamura & Fujita, 1991; Ashton *et al.*, 1991; Fujita *et al.*, 1992). Any mechanistic ambiguities that may have arisen from the S_N2 reaction with azide ions was clarified by X-ray crystallographic analysis, which confirmed the structure of the title compound as described below.

2. Structural commentary

In compound **3** (Fig. 1), the tetrahydrofuran (THF) ring is best described as twisted with atoms C3 and C4 displaced by 0.169 (3) and -0.384 (2) Å, respectively, from the plane through C5/C6/O1. The fused dioxolane ring adopts an

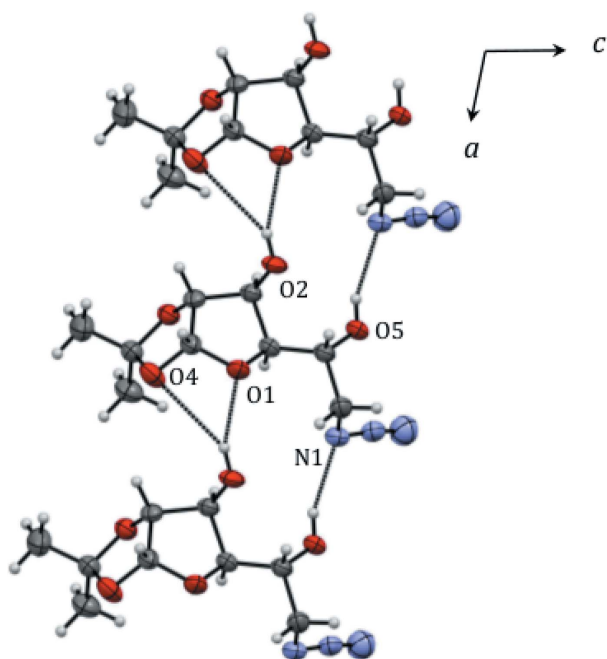


Figure 2
Partial packing diagram for **3** showing hydrogen bonds as dashed lines.

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

<i>D</i> —H··· <i>A</i>	<i>D</i> —H	H··· <i>A</i>	<i>D</i> ··· <i>A</i>	<i>D</i> —H··· <i>A</i>
O2—H2A···O1 ⁱ	0.84	2.09	2.871 (2)	154
O2—H2A···O4 ⁱ	0.84	2.71	3.462 (2)	150
O5—H5A···N1 ⁱ	0.84	2.12	2.910 (3)	157
C6—H6···O5 ⁱⁱ	1.00	2.38	3.332 (3)	159

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

envelope conformation with O3 displaced by 0.402 (2) Å from the mean plane of the other ring atoms (C5/C6/O4/C7; r.m.s. deviation = 0.005 Å). The dihedral angle between the five-membered rings (all atoms) is 67.50 (13)°. The hydroxyl group O2—H2A and the acetonide oxygen atom O3 project axially from the THF ring, lying respectively above and below in a *trans* arrangement from one another [O2—C4—C5—O3 = 164.46 (18)°]. The other two groups projecting from the THF ring are O4 of the acetonide and the side chain attached to C3, which sit equatorially. The absolute structure of **3** was not definitively established in the refinement but the configurations of the stereogenic atoms (C2 *R*, C3 *R*, C4 *S*, C5 *R* and C6 *R*) were set to match those of the starting material.

3. Supramolecular features

There are no intramolecular hydrogen-bonding interactions in **3** but both hydroxyl groups participate in intermolecular hydrogen-bonding interactions (Table 1, Fig. 2), which generate chains propagating parallel to the *a*-axis direction. The O5 hydroxyl group donates a hydrogen bond to the proximal azide N atom [O5—H5A···N1ⁱ; H···N = 2.12 Å; O—H···N = 157°; symmetry code: (i) $x - 1, y, z$]. The other group (O2) is involved in an asymmetric, bifurcated hydrogen-bond to the THF ring O atom (O2—H2A···O1ⁱ; 2.09 Å; 154°) and a weaker contact with one of the dioxolane O-atoms (O2—H2A···O4ⁱ; 2.71 Å; 150°). There is a notable non-classical hydrogen-bond [C6—H6···O5ⁱⁱ; 2.38 Å; 159°; symmetry code: (ii) $-x, y - \frac{1}{2}, -z + 2$], which cross-links the [100] chains into (001) sheets.

4. Database survey

The most closely related crystal structure in the literature is **4** (Fig. 3), the 4-cyclopropyl-1,2,3-triazole derivative of compound **3** [Zhang *et al.*, 2013, Cambridge Structural Database (Groom *et al.*, 2016) refcode NINQOS] synthesized from

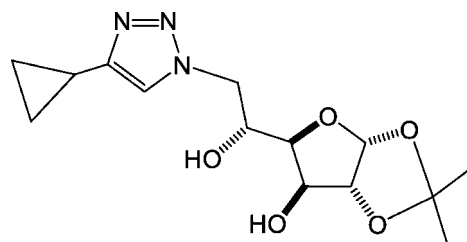


Figure 3
Structure of **4** (see text).

a copper-catalysed azide–alkyne cycloaddition of the tribenzyl ether analogue of **3** followed by deprotection with NH_3/NaOH (Pradere *et al.*, 2008). Conversion of the azide to a triazole removes the hydrogen-bonding capability of the proximal N atom and the packing in this structure is distinctly different with a hydrogen-bonded network being present. Other points of difference in structure **4** relative to **3** include the free hydroxyl group on the THF ring, which adopts an axial conformation, and the dioxolane ring methyl groups tilted closer to the THF ring.

Other examples of crystal structures of α -D-glucofuranose derivatives constrained by a 1,2-*O*-isopropylidene or analogous protecting group include: 3-*O*-ethyl-3-*C*-nitromethyl-1,2;5,6-di-*O*-isopropylidene- α -D-glucofuranose (Ivanovs *et al.*, 2016; QENNEF) and 3-*O*-benzyl-1,2-*O*-isopropylidene-5-*O*-methanesulfonyl-6-*O*-triphenyl-methyl- α -D-glucofuranose and its azide displacement product (Clarke *et al.*, 2018; QIBFUF). A general observation is that groups departing from O-3 take up axial or quasi-axial orientations relative to the THF ring in all cases examined and as is the case for the 3-*O*-ethyl group in QENNEF and the benzyl groups in QIBFUF and (4*R*)-4-carbamoyl-4-[(4*R*)-3-*O*-benzyl-1,2-*O*-isopropylidene- β -L-threofuranos-4-*C*-yl]-oxazolidin-2-one (Steiner *et al.*, 2009) and the tosylate group in 1,2;5,6-di-*O*-isopropylidene-3-*O*-toluenesulfonyl- α -D-glucofuranose (Mamat *et al.*, 2012). The impact of perfluorination on the conformation of monosaccharide derivatives was probed on (*R/S*)-*N*-benzyl-*N*-(5-deoxy-1,2-*O*-isopropylidene-3-*O*-methyl- α -D-xylofuranos-5-yl)-2,3,3,3-tetrafluoropropanamide and analogous compounds (Bilska-Markowska *et al.*, 2017). The crystal structures of α -D-glucofuranose-1,2,3,5-bis(phenyl)boronate and α -D-glucofuranose-1,2,3,5-bis(*p*-tolyl)boronate highlight modulation in structures according to a temperature gradient (Chandran & Nangia, 2006). The structure of chloro(cyclopentadienyl)bis(1,2;5,6-di-*O*-isopropylidene- α -D-glucofuranos-3-*O*-yl)titanate provides insight into the use of monosaccharides as ligands in complexes. The titanium atom is bonded to two monosaccharide OH-3, in axial positions, a cyclopentadienyl and a chloride ligand, to take up a three-legged piano stool arrangement (Riediker *et al.*, 1989). The unit cell of (*R*)-3-deoxy-1,2;5,6-di-*O*-isopropylidene- α -D-glucofuranos-3-yl-*tert*-butanesulfinate contains four symmetry-independent molecules with the *tert*-butyl and glucose moieties turned away from each other in order to minimize steric repulsion (Chelouan *et al.*, 2018).

5. Synthesis and crystallization

1,2-*O*-Isopropylidene-6-*O*-*p*-toluenesulfonyl- α -D-glucofuranose, **2**:

A solution of freshly recrystallized tosyl chloride (0.479 g, 2.55 mmol) in DCM (1.6 ml) was added dropwise over 20 min to a stirring solution of 1,2-*O*-isopropylidene- α -D-glucofuranose **1** (0.513 g, 2.32 mmol) in pyridine (3.8 ml) and DCM (4.2 ml), under an atmosphere of nitrogen. The reaction was stirred at room temperature for 48 h. TLC analysis (EtOAc/cyclohexane 2:3) revealed the formation of one product (R_f =

Table 2
Experimental details.

Crystal data	
Chemical formula	$\text{C}_9\text{H}_{15}\text{N}_3\text{O}_5$
M_r	245.24
Crystal system, space group	Monoclinic, $P2_1$
Temperature (K)	190
a, b, c (Å)	5.7615 (4), 9.7752 (8), 10.6833 (9)
β (°)	101.255 (8)
V (Å ³)	590.11 (8)
Z	2
Radiation type	Cu $K\alpha$
μ (mm ⁻¹)	0.97
Crystal size (mm)	0.40 × 0.30 × 0.02
Data collection	
Diffractometer	Rigaku Xcalibur, EosS2, Gemini ultra
Absorption correction	Multi-scan (<i>CrysAlis PRO</i> ; Rigaku, 2015)
$T_{\text{min}}, T_{\text{max}}$	0.741, 1
No. of measured, independent and observed [$I > 2\sigma(I)$] reflections	3705, 1788, 1674
R_{int}	0.044
θ_{max} (°)	61.5
$(\sin \theta/\lambda)_{\text{max}}$ (Å ⁻¹)	0.570
Refinement	
$R[F^2 > 2\sigma(F^2)], wR(F^2), S$	0.036, 0.086, 1.08
No. of reflections	1788
No. of parameters	156
No. of restraints	1
H-atom treatment	H-atom parameters constrained
$\Delta\rho_{\text{max}}, \Delta\rho_{\text{min}}$ (e Å ⁻³)	0.13, -0.15
Absolute structure	Flack (1983)
Absolute structure parameter	-0.4 (3)

Computer programs: *CrysAlis PRO* (Rigaku, 2015), *SIR92* (Altomare *et al.*, 1994), *SHELXL97* (Sheldrick, 2008), *ORTEP-3 for Windows* and *WinGX* publication routines (Farrugia, 2012).

0.45). After adding DCM (10 ml), the reaction mixture was washed with 1 *M* HCl (1 ml). The DCM layer was dried to give 1,2-*O*-isopropylidene-6-*O*-*p*-toluenesulfonyl- α -D-glucofuranose **2** (0.282 g, 32%) as an off-white crystalline solid. δ_{H} (CDCl_3 , 400 MHz) 7.79 (2H, *d*, J = 8.3 Hz, 2 Ar-H), 7.35 (2H, *d*, J = 8.1 Hz, 2 Ar-H), 5.88 (1H, *d*, J = 3.6 Hz, H-1), 4.50 (1H, *d*, J = 3.6 Hz, H-2), 4.36 (1H, *d*, J = 2.7 Hz, H-3), 4.29 (1H, *dd*, J = 10.2, 2.5 Hz, H-6), 4.19 (1H, *td*, J = 7.7, 2.5 Hz, H-5), 4.11 (1H, *dd*, J = 10.2, 6.8 Hz, H-6'), 4.01 (1H, *dd*, J = 7.7, 2.7 Hz, H-4), 2.45 (3H, *s*, Ar-CH₃), 1.45, 1.29 (6H, 2 *s*, 2 acetonide CH₃). δ_{C} (acetone-*d*₆, 100 MHz): 145.2 (ArCq-S), 132.3 (ArCq-CH₃), 130.0 (2 ArC), 128.0 (2 ArC), 111.9 (Cq acetonide), 105.1 (C-1), 85.0 (C-2), 79.4 (C-4), 75.0 (C-3), 72.1 (C-6), 68.0 (C-5), 26.8 (acetonide CH₃), 26.2 (acetonide CH₃), 21.7 (Ar-CH₃); ν_{max} (cm⁻¹): 3426, 3322, 2979, 2928, 1378, 1215, 1162, 1058, 1037, 1007, 962, 883, 850, 673, 657, 626.

6-Azido-6-deoxy-1,2-*O*-isopropylidene- α -D-glucofuranose, **3**:

Sodium azide (0.290 g, 4.46 mmol) was added to a stirring solution of **2** (1.668 g, 4.45 mmol) in DMF (18 ml) at room temperature. The reaction mixture was then heated to 358 K for 42 h. TLC analysis (EtOAc/cyclohexane 2:3) revealed complete consumption of the starting material (R_f = 0.45) and the formation of one product (R_f = 0.30). The crude product was dried and successively dissolved in 1,4-dioxane with

addition of hexane to yield an off-white precipitate, which was filtered off. The remaining filtrate contained 6-azido-6-deoxy-1,2-*O*-isopropylidene- α -D-glucofuranose, **3**. Crystallization was achieved overnight at 248 K, after dissolution in diethyl ether with addition of hexane. The ether–hexane solution was recrystallized to obtain 2nd and 3rd crops of product to yield a combined 0.319 g (29%) of product **3** as a white crystalline solid. δ_{H} (CDCl₃, 400 MHz): 5.95 (1H, *d*, *J* = 3.7 Hz, H-1), 4.53 (1H, *d*, *J* = 3.6 Hz, H-2), 4.37 (1H, *d*, *J* = 2.8 Hz, H-3), 4.16 (1H, *td*, *J* = 6.6, 3.6 Hz, H-5), 4.05 (1H, *dd*, *J* = 6.6, 2.8 Hz, H-4), 3.61 (1H, *dd*, *J* = 12.7, 3.5 Hz, H-6), 3.55 (1H, *dd*, *J* = 12.7, 6.5 Hz, H-6'), 1.49, 1.32 (6H, 2 *s*, 2 acetonide CH₃). ν_{max} (cm⁻¹): 3442, 2992, 2938, 2109, 1385, 1376, 1215, 1164, 1066, 1048, 1008, 955, 881, 854, 788, 674.

6. Refinement

Crystal data, data collection and structure refinement details are summarized in Table 2. All H atoms were positioned geometrically (O–H = 0.84, C–H = 0.98–1.00 Å) and refined as riding with $U_{\text{iso}}(\text{H}) = 1.2U_{\text{eq}}(\text{O,C})$ or $1.5U_{\text{eq}}(\text{C-methyl})$.

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supporting information

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Crystal structure of 6-azido-6-deoxy-1,2-*O*-isopropylidene- α -D-glucofuranose

Adam Wood, Paul V. Bernhardt, Ian van Altena and Michela I. Simone

Computing details

Data collection: *CrysAlis PRO* (Rigaku, 2015); cell refinement: *CrysAlis PRO* (Rigaku, 2015); data reduction: *CrysAlis PRO* (Rigaku, 2015); program(s) used to solve structure: *SIR92* (Altomare *et al.*, 1994); program(s) used to refine structure: *SHELXL97* (Sheldrick, 2008); molecular graphics: *ORTEP-3 for Windows* (Farrugia, 2012); software used to prepare material for publication: *WinGX* publication routines (Farrugia, 2012).

6-Azido-6-deoxy-1,2-*O*-isopropylidene- α -D-glucofuranose

Crystal data

$C_9H_{15}N_3O_5$

$M_r = 245.24$

Monoclinic, $P2_1$

Hall symbol: P 2yb

$a = 5.7615$ (4) Å

$b = 9.7752$ (8) Å

$c = 10.6833$ (9) Å

$\beta = 101.255$ (8)°

$V = 590.11$ (8) Å³

$Z = 2$

$F(000) = 260$

$D_x = 1.38$ Mg m⁻³

Cu $K\alpha$ radiation, $\lambda = 1.54184$ Å

Cell parameters from 1783 reflections

$\theta = 6.2$ – 60.6 °

$\mu = 0.97$ mm⁻¹

$T = 190$ K

Plate, colourless

$0.40 \times 0.30 \times 0.02$ mm

Data collection

Rigaku Xcalibur, EosS2, Gemini ultra diffractometer

Radiation source: fine-focus sealed X-ray tube
Graphite monochromator

Detector resolution: 8.0217 pixels mm⁻¹

ω scans

Absorption correction: multi-scan
(*CrysAlisPro*; Rigaku, 2015)

$T_{\min} = 0.741$, $T_{\max} = 1$

3705 measured reflections

1788 independent reflections

1674 reflections with $I > 2\sigma(I)$

$R_{\text{int}} = 0.044$

$\theta_{\max} = 61.5$ °, $\theta_{\min} = 4.2$ °

$h = -6 \rightarrow 6$

$k = -11 \rightarrow 10$

$l = -12 \rightarrow 12$

Refinement

Refinement on F^2

Least-squares matrix: full

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

$wR(F^2) = 0.086$

$S = 1.08$

1788 reflections

156 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-atom parameters constrained

$w = 1/[\sigma^2(F_o^2) + (0.0346P)^2 + 0.0212P]$

where $P = (F_o^2 + 2F_c^2)/3$

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

$\Delta\rho_{\max} = 0.13$ e Å⁻³

$\Delta\rho_{\min} = -0.14$ e Å⁻³

Absolute structure: Flack (1983)

Absolute structure parameter: -0.4 (3)*Special details*

Geometry. All s.u.'s (except the s.u. in the dihedral angle between two l.s. planes) are estimated using the full covariance matrix. The cell s.u.'s are taken into account individually in the estimation of s.u.'s in distances, angles and torsion angles; correlations between s.u.'s in cell parameters are only used when they are defined by crystal symmetry. An approximate (isotropic) treatment of cell s.u.'s is used for estimating s.u.'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 $F^2 > 2\sigma(F^2)$ 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)

	<i>x</i>	<i>y</i>	<i>z</i>	$U_{\text{iso}}^*/U_{\text{eq}}$
C1	0.3329 (4)	0.6279 (3)	1.2308 (2)	0.0428 (6)
H1A	0.3365	0.5953	1.3189	0.051*
H1B	0.4098	0.5574	1.1863	0.051*
C2	0.0786 (4)	0.6435 (2)	1.1633 (2)	0.0345 (5)
H2	-0.0043	0.5539	1.1654	0.041*
C3	0.0532 (4)	0.6893 (3)	1.0256 (2)	0.0329 (5)
H3	0.1366	0.7784	1.0212	0.04*
C4	-0.2022 (4)	0.6991 (2)	0.9528 (2)	0.0340 (5)
H4	-0.2721	0.7914	0.9614	0.041*
C5	-0.1750 (4)	0.6702 (2)	0.8164 (2)	0.0342 (5)
H5	-0.3207	0.6292	0.7634	0.041*
C6	0.0389 (4)	0.5759 (3)	0.8297 (2)	0.0357 (5)
H6	-0.0087	0.4799	0.8045	0.043*
C7	0.0728 (4)	0.7525 (3)	0.6883 (2)	0.0393 (6)
C8	0.2544 (5)	0.8648 (3)	0.7005 (3)	0.0524 (7)
H8A	0.3755	0.8406	0.6514	0.079*
H8B	0.3287	0.8765	0.7905	0.079*
H8C	0.1774	0.9504	0.6675	0.079*
C9	-0.0399 (6)	0.7197 (4)	0.5530 (3)	0.0654 (9)
H9A	0.0828	0.6935	0.5056	0.098*
H9B	-0.1246	0.8003	0.513	0.098*
H9C	-0.1514	0.6438	0.5518	0.098*
N1	0.4698 (3)	0.7562 (3)	1.2362 (2)	0.0498 (6)
N2	0.4455 (3)	0.8362 (3)	1.3223 (2)	0.0464 (5)
N3	0.4413 (5)	0.9168 (3)	1.3977 (3)	0.0654 (7)
O1	0.1584 (3)	0.58380 (19)	0.95897 (16)	0.0426 (4)
O2	-0.3347 (3)	0.5933 (2)	0.99674 (16)	0.0460 (4)
H2A	-0.4782	0.6016	0.9625	0.069*
O3	-0.0999 (3)	0.79118 (16)	0.76079 (15)	0.0386 (4)
O4	0.1823 (3)	0.63255 (19)	0.74985 (18)	0.0497 (5)
O5	-0.0267 (3)	0.74186 (18)	1.23341 (15)	0.0390 (4)
H5A	-0.1747	0.7349	1.2142	0.059*

Atomic displacement parameters (\AA^2)

	U^{11}	U^{22}	U^{33}	U^{12}	U^{13}	U^{23}
C1	0.0349 (12)	0.0567 (16)	0.0369 (12)	0.0109 (11)	0.0075 (9)	0.0070 (11)
C2	0.0268 (11)	0.0403 (13)	0.0379 (12)	0.0022 (10)	0.0099 (9)	0.0035 (10)
C3	0.0271 (12)	0.0395 (12)	0.0340 (12)	0.0030 (9)	0.0105 (9)	-0.0009 (10)
C4	0.0246 (12)	0.0409 (13)	0.0376 (12)	0.0017 (9)	0.0086 (10)	0.0029 (10)
C5	0.0257 (12)	0.0402 (14)	0.0352 (12)	-0.0063 (9)	0.0027 (9)	-0.0005 (10)
C6	0.0323 (12)	0.0412 (13)	0.0349 (12)	-0.0046 (10)	0.0094 (9)	-0.0029 (10)
C7	0.0339 (13)	0.0491 (14)	0.0368 (13)	0.0019 (11)	0.0112 (10)	0.0015 (11)
C8	0.0435 (14)	0.0534 (18)	0.0639 (18)	-0.0069 (12)	0.0193 (13)	0.0006 (14)
C9	0.0598 (18)	0.094 (3)	0.0432 (16)	-0.0117 (17)	0.0118 (13)	-0.0108 (15)
N1	0.0259 (11)	0.0806 (18)	0.0433 (12)	-0.0012 (10)	0.0075 (9)	-0.0069 (12)
N2	0.0298 (10)	0.0663 (16)	0.0419 (13)	0.0060 (10)	0.0042 (9)	0.0052 (12)
N3	0.0656 (16)	0.0718 (17)	0.0578 (16)	0.0104 (13)	0.0099 (12)	-0.0061 (15)
O1	0.0278 (8)	0.0598 (11)	0.0404 (9)	0.0128 (8)	0.0071 (6)	-0.0047 (8)
O2	0.0220 (7)	0.0654 (11)	0.0521 (10)	-0.0030 (8)	0.0110 (7)	0.0101 (9)
O3	0.0346 (8)	0.0432 (10)	0.0396 (9)	0.0038 (7)	0.0110 (7)	0.0045 (7)
O4	0.0467 (10)	0.0532 (11)	0.0569 (11)	0.0106 (8)	0.0292 (8)	0.0106 (8)
O5	0.0269 (8)	0.0532 (11)	0.0389 (9)	0.0031 (7)	0.0113 (7)	-0.0032 (8)

Geometric parameters (\AA , $^\circ$)

C1—N1	1.477 (4)	C6—O1	1.420 (3)
C1—C2	1.509 (3)	C6—H6	1
C1—H1A	0.99	C7—O3	1.427 (3)
C1—H1B	0.99	C7—O4	1.429 (3)
C2—O5	1.425 (3)	C7—C9	1.499 (4)
C2—C3	1.517 (3)	C7—C8	1.505 (4)
C2—H2	1	C8—H8A	0.98
C3—O1	1.451 (3)	C8—H8B	0.98
C3—C4	1.527 (3)	C8—H8C	0.98
C3—H3	1	C9—H9A	0.98
C4—O2	1.419 (3)	C9—H9B	0.98
C4—C5	1.522 (3)	C9—H9C	0.98
C4—H4	1	N1—N2	1.236 (3)
C5—O3	1.428 (3)	N2—N3	1.131 (4)
C5—C6	1.523 (3)	O2—H2A	0.84
C5—H5	1	O5—H5A	0.84
C6—O4	1.411 (3)		
N1—C1—C2	113.2 (2)	O4—C6—C5	105.36 (19)
N1—C1—H1A	108.9	O1—C6—C5	106.73 (17)
C2—C1—H1A	108.9	O4—C6—H6	111.6
N1—C1—H1B	108.9	O1—C6—H6	111.6
C2—C1—H1B	108.9	C5—C6—H6	111.6
H1A—C1—H1B	107.8	O3—C7—O4	105.03 (18)
O5—C2—C1	106.9 (2)	O3—C7—C9	111.3 (2)

O5—C2—C3	109.89 (18)	O4—C7—C9	109.7 (2)
C1—C2—C3	113.22 (17)	O3—C7—C8	107.8 (2)
O5—C2—H2	108.9	O4—C7—C8	108.8 (2)
C1—C2—H2	108.9	C9—C7—C8	113.7 (2)
C3—C2—H2	108.9	C7—C8—H8A	109.5
O1—C3—C2	107.18 (18)	C7—C8—H8B	109.5
O1—C3—C4	104.35 (18)	H8A—C8—H8B	109.5
C2—C3—C4	114.43 (17)	C7—C8—H8C	109.5
O1—C3—H3	110.2	H8A—C8—H8C	109.5
C2—C3—H3	110.2	H8B—C8—H8C	109.5
C4—C3—H3	110.2	C7—C9—H9A	109.5
O2—C4—C5	110.12 (19)	C7—C9—H9B	109.5
O2—C4—C3	108.23 (18)	H9A—C9—H9B	109.5
C5—C4—C3	101.95 (16)	C7—C9—H9C	109.5
O2—C4—H4	112	H9A—C9—H9C	109.5
C5—C4—H4	112	H9B—C9—H9C	109.5
C3—C4—H4	112	N2—N1—C1	115.41 (19)
O3—C5—C4	109.89 (18)	N3—N2—N1	173.0 (3)
O3—C5—C6	103.56 (16)	C6—O1—C3	110.24 (17)
C4—C5—C6	104.82 (18)	C4—O2—H2A	109.5
O3—C5—H5	112.6	C7—O3—C5	107.83 (18)
C4—C5—H5	112.6	C6—O4—C7	110.02 (17)
C6—C5—H5	112.6	C2—O5—H5A	109.5
O4—C6—O1	109.68 (18)		
N1—C1—C2—O5	-60.8 (2)	C4—C5—C6—O1	-15.1 (2)
N1—C1—C2—C3	60.3 (3)	C2—C1—N1—N2	81.8 (3)
O5—C2—C3—O1	-178.66 (18)	C1—N1—N2—N3	172 (2)
C1—C2—C3—O1	61.9 (3)	O4—C6—O1—C3	106.5 (2)
O5—C2—C3—C4	-63.5 (3)	C5—C6—O1—C3	-7.2 (2)
C1—C2—C3—C4	177.1 (2)	C2—C3—O1—C6	148.18 (18)
O1—C3—C4—O2	81.9 (2)	C4—C3—O1—C6	26.5 (2)
C2—C3—C4—O2	-34.9 (3)	O4—C7—O3—C5	-28.5 (2)
O1—C3—C4—C5	-34.2 (2)	C9—C7—O3—C5	90.2 (3)
C2—C3—C4—C5	-151.02 (19)	C8—C7—O3—C5	-144.4 (2)
O2—C4—C5—O3	164.46 (17)	C4—C5—O3—C7	139.25 (18)
C3—C4—C5—O3	-80.8 (2)	C6—C5—O3—C7	27.7 (2)
O2—C4—C5—C6	-84.8 (2)	O1—C6—O4—C7	-115.1 (2)
C3—C4—C5—C6	29.9 (2)	C5—C6—O4—C7	-0.5 (2)
O3—C5—C6—O4	-16.5 (2)	O3—C7—O4—C6	17.4 (2)
C4—C5—C6—O4	-131.67 (19)	C9—C7—O4—C6	-102.3 (2)
O3—C5—C6—O1	100.11 (19)	C8—C7—O4—C6	132.7 (2)

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

<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>
O2—H2A \cdots O1 ⁱ	0.84	2.09	2.871 (2)	154
O2—H2A \cdots O4 ⁱ	0.84	2.71	3.462 (2)	150

O5—H5A···N1 ⁱ	0.84	2.12	2.910 (3)	157
C6—H6···O5 ⁱⁱ	1.00	2.38	3.332 (3)	159

Symmetry codes: (i) $x-1, y, z$; (ii) $-x, y-1/2, -z+2$.