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Synthesis, crystal structure and Hirshfeld surface analysis of Fmoc-β-amino butyric acid and Fmoc carbamate

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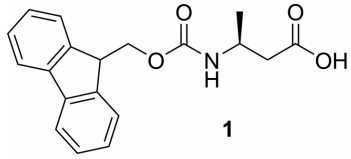
In the context of the development of synthetic routes that facilitate the incorporation of β-amino acids into peptide synthesis, the synthesis, crystal structure and Hirshfeld surface analysis are reported of fluorenylmethoxycarbonyl (Fmoc) protected β-amino butyric acid, namely, 3-{[(9*H*-fluoren-9-ylmethoxy)-carbonyl]amino}butanoic acid, $C_{19}H_{19}NO_4$. The importance of pH control in the reaction employing Fmoc-N_3 is demonstrated with another β-amino acid analogue from which Fmoc carbamate was identified as the major product.

1. Chemical context

The increasing application of non-natural amino acids, particularly β-amino acids, in drug development, specifically peptide drugs necessitates the development of an economical and cost-effective method for producing modified β-amino acids. Modern peptide synthesis predominantly employs solid-phase peptide synthesis (SPPS) using the Fmoc strategy to mask the reactivity of the amine group with a temporary protective group (Behrendt *et al.*, 2016). Peptide chain elongation can then be performed through sequential cycles involving the removal of the protective group, followed by the coupling of *N*-protected amino acids (Hlebowicz *et al.*, 2005; Isidro-Llobet *et al.*, 2007). This strategy allows efficient and controlled peptide assembly. Fmoc chemistry, while seemingly straightforward, presents challenges, particularly with β-amino acids due to the additional α-carbon, which serves as a potential reactive site. During the optimization of the synthesis of Fmoc-β-amino acids using alternatives to Fmoc-Cl, Fmoc-*R*-β-aminobutyric acid (Fmoc-*R*-βABA) **1** was synthesized to a high yield and purity after the *in situ* preparation of Fmoc-N_3 (Cruz *et al.*, 2004). When the same technique was applied to the synthesis of Fmoc-DL-β-phenylalanine, Fmoc-carbamate **2** was obtained.



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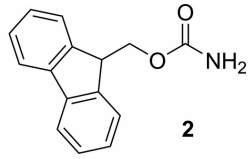

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2. Structural commentary

Compound **1** crystallizes in the orthorhombic space group $P2_12_12_1$, its asymmetric unit comprising of a single molecule (Fig. 1). The tricyclic fluorenyl group is planar (r.m.s. deviation 0.025 Å). The carbamate group adopts the *trans* geometry and is planar (r.m.s. deviation 0.005 Å). The absolute configuration

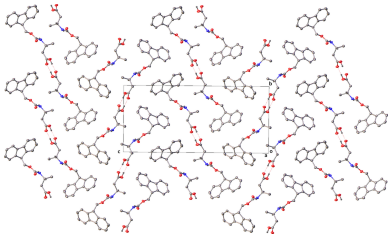

Table 1
Hydrogen-bond geometry (Å, °) for **1**.

D—H···A	D—H	H···A	D···A	D—H···A
O4—H4···O3^{i}	0.94 (4)	1.72 (4)	2.656 (2)	177 (3)
N1—H1···O1^{ii}	0.88 (3)	2.04 (3)	2.844 (3)	152 (2)

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

of an *R* stereogenic centre is confirmed to a high degree of certainty. The Hooft parameter of −0.05 (14) demonstrates that a single enantiomer is present. Compound **2** crystallizes in the orthorhombic space group $Pca2_1$, its asymmetric unit comprising of two molecules (Fig. 2). The two tricyclic fluorenyl groups are both planar (r.m.s. deviation of C16–C28 = 0.020 Å and C1–C13 = 0.025 Å). The carbamate group is planar (r.m.s. deviation 0.001 Å). The absolute configuration of an *R* stereogenic centre is confirmed to a high degree of certainty. The Hooft parameter of −0.05 (14) demonstrates that a single enantiomer is present.

3. Supramolecular features

In the molecular packing of crystal **1** (Fig. 3), two hydrogen-bonded (Table 1) chains are observed (Fig. 4). One chain forms from the carbamate hydrogen atom (H1) and the carbonyl oxygen atom (O1) of an adjacent molecule (−1 + *x*, *y*, *z*) and continues parallel to the *a* axis (Fig. 4). The second

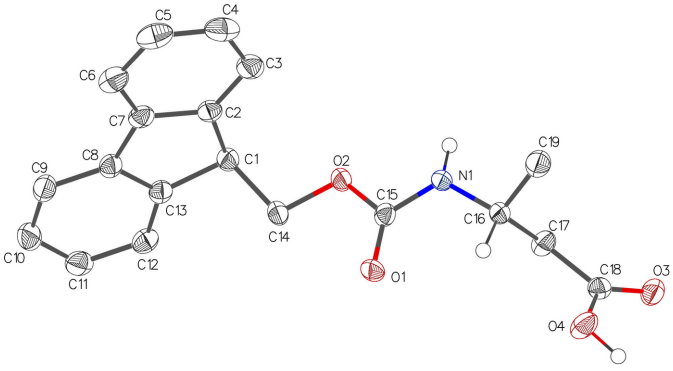

Figure 1
The molecular structure of Fmoc-*β*-amino butyric acid **1** showing 50% displacement ellipsoids

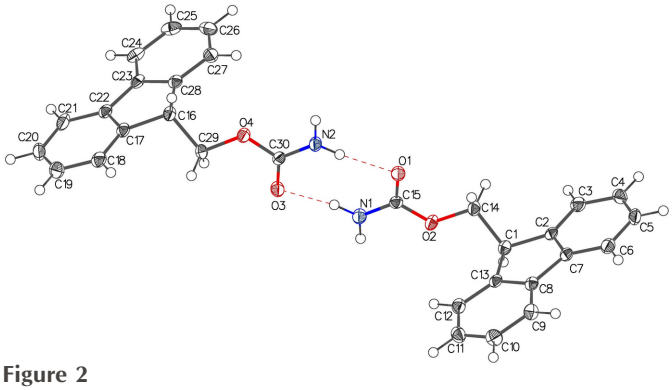

Figure 2
The molecular structure of Fmoc carbamate **2** showing 50% displacement ellipsoids

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

D—H···A	D—H	H···A	D···A	D—H···A
N1—H1B···O3	0.91 (3)	2.06 (3)	2.955 (3)	169 (3)
N1—H1A···O1^{i}	0.86 (3)	2.08 (3)	2.849 (3)	149 (3)
N2—H2A···O1	0.85 (3)	2.13 (3)	2.967 (3)	169 (3)
N2—H2B···O3^{ii}	0.87 (4)	2.03 (4)	2.827 (3)	152 (3)

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

chain observed is formed by the carboxylic acid group hydrogen atom (H4) and the carbonyl oxygen atom (O3) of the adjacent molecule $(\frac{1}{2}+x, \frac{1}{2}-y, 1-z)$. These chains are not linear but have an angle of 47.9 (10)° between the carboxylic acid planes of each molecule. Hydrogen-bond statistical analysis (*Mercury* 2024.1.0; Macrae *et al.*, 2020) was performed, which highlighted the hydrogen bonds to be not unusual. The transamide chain hydrogen bond [2.844 (2) Å] is a little below average in distance (2.97 Å) from 1428 hits. The carboxylic acid chain hydrogen bond [2.656 (2) Å] was found to be of average distance (2.66 Å) from 3072 hits.

Strong face–face *π*–*π* interactions (as investigated with the CSD Materials Aromatics Analyser tool) are observed in the packing of **1**, running parallel to the *a* axis. The rings C1–C6 and C8–13 form columns stacking on top and below with symmetry equivalents (*x*, *y*, *z* and −1 + *x*, *y*, *z*), with a centroid–centroid distance of 4.8393 (2) Å and twist plane angle of 0.0 (3)°. These interactions can be visualised later in

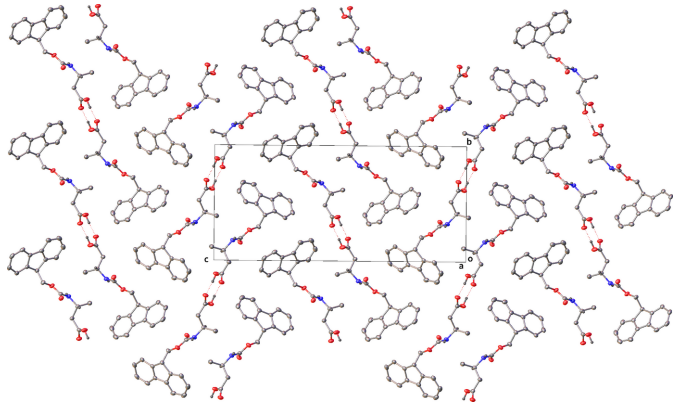

Figure 3
Packing of **1** as viewed along the *a* axis

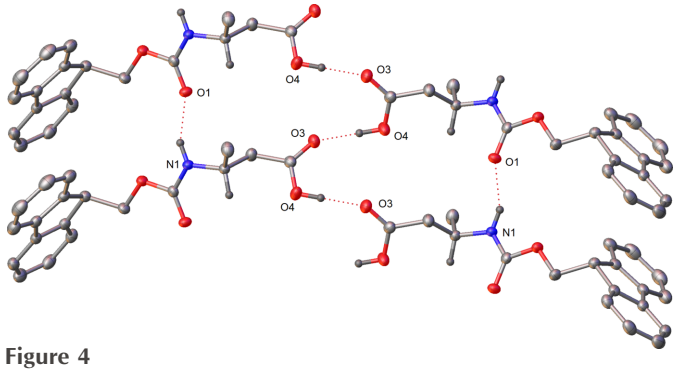

Figure 4
Hydrogen bonding present in **1**

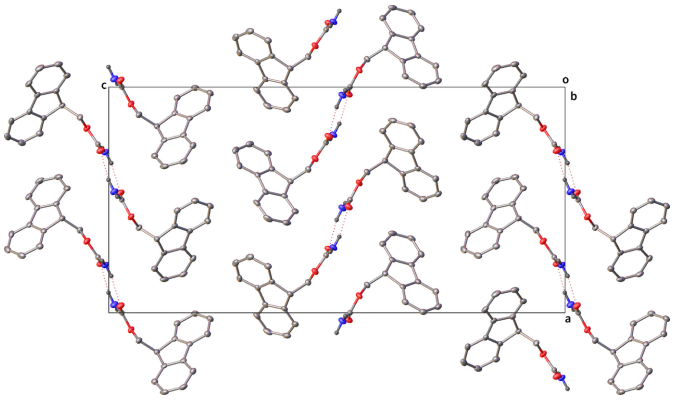

Figure 5
Packing of **2** as viewed along the *b* axis

the Hirshfield surface analysis plot (Fig. 7, 2nd from top) showing the C···H/H···C interactions primarily around the Fmoc group.In the molecular packing of crystal **2** (Fig. 5), the two molecules in the asymmetric unit dimerize with hydrogen bonds (Table 2) formed between the carbamate hydrogen atom (H2*A*) and oxygen atom (O1), as well as the carbamate hydrogen atom (H1*B*) and oxygen atom (O3). The other carbamate hydrogen atoms of each of the two molecules then form a further hydrogen bond to an adjacent molecule to form a 1D hydrogen-bonded network (Fig. 6). The carbamate hydrogen atom (H1*A*) forms a hydrogen bond with oxygen atom (O1) (x, $-1+y$, z) and the carbamate hydrogen atom (H2*B*) with oxygen atom (O3) (x, $1+y$, z). Hydrogen-bond statistical analysis (*Mercury* 2024.1.0; Macrae *et al.*, 2020) was performed, which allowed comparison to 3268 structures. This showed that the dimeric hydrogen bonds (N2—H2*A*···O1) and (N1—H1*B*···O3) were not unusual. The hydrogen bonds (N1—H1*A*···O1) and (N2—H2*B*···O3) were found to be unusual on account of their hydrogen bonds having shorter lengths and more acute angles [2.8549 (3) Å, 149 (3)° and 2.827 (3) Å, 152 (3)°, respectively] below the mean (2.94 Å and 173.35°). A strong face–face π–π interaction is observed in the packing of **2** between the rings C17–C22 and C23–-28 (x, $-1+y$, z) as well as between C2–C7 and C8–C13(x, $1+y$, z) columns stacking on top and below with symmetry equivalents), with a centroid–centroid distance of 4.4182 (15) Å and relative orientation of 2.55 (9)°. These interactions can also be visualised later in the Hirshfield surface analysis plot (Fig. 8, 2nd from top) showing the ···H/H···C interactions around the Fmoc group.

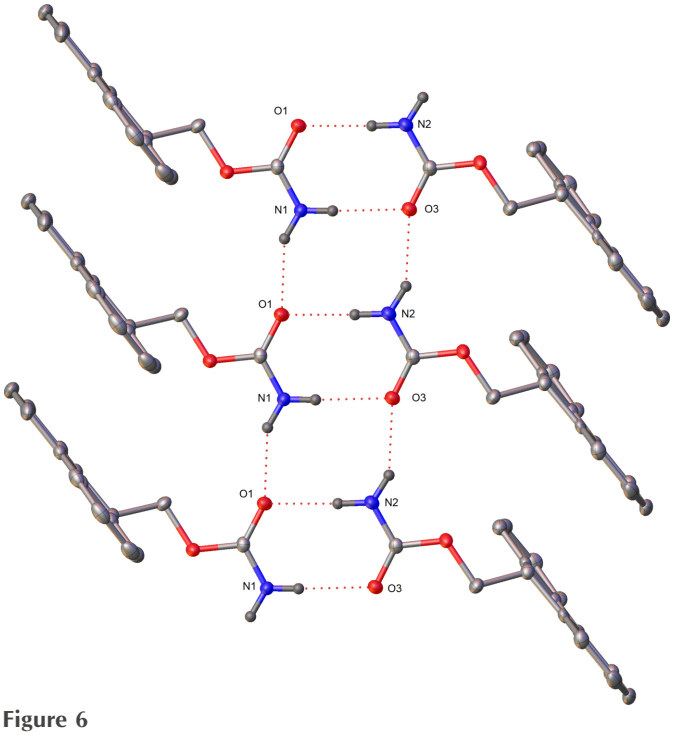

Figure 6
Hydrogen bonding between the carbamate groups present in **2**

4. Database survey

A search of the Cambridge Structural Database (CSD version 5.46, November 2024; Groom *et al.*, 2016) highlighted that the crystal structures of compounds **1** and **2** have not been reported. Searches for structural motifs similar to **1** began with Fmoc-protected α-amino acids and discovered 51 results of various natural amino acids, synthetic derivatives and co-crystals, the most closely related structure being CUWKIO (Valle *et al.*, 1984), a Fmoc-protected alanine monohydrate that differs in structure by the one carbon atom as well as co-crystallizing with a molecule of water. Despite crystallizing in the same space group as **1**, CUWKIO has a different set of hydrogen bonds formed within the crystal structure. Instead of the amide hydrogen-bonded chains seen in **1**, the amide H atom of CUWKIO forms a hydrogen bond to the carboxylic acid carbonyl whereas the co-crystallized water forms a hydrogen bond to the amide carbonyl. The co-crystallized water then satisfies its remaining hydrogen-bond formation with the carboxylic acid carbonyl and the carboxylic acid hydrogen is satisfied by forming a hydrogen bond to the water. In total, four hydrogen bonds are reported in CUWKIO in contrast to **1**, which has two. Aromatic interactions, as investigated with the CSD Materials Aromatics Analyser tool, highlight a change in packing of the π–π interactions of the Fmoc groups. Strong face-face interactions in **1** are no longer present but instead strong edge-to-face interactions seen in CUWKIO. Further investigation of structural similarities lead us to look for Fmoc-protected β-amino acids, the structural motif of which was found the related structure BOMRAY (Ahmad Wani *et al.*, 2014), which differs as there is a spiro-centred carbon with cyclic six-membered ring at the β carbon, in contrast to **1**, which has the methyl group as well as being a racemate. BOMRAY crystallises in the $P\overline{1}$ space group and the primary hydrogen-bond interactions are a not unusual dimerization of the carboxylic acid as well as a long amide N—H to carboxylic acid carbonyl bond. The amide carbonyl in this case only forms a long weak intermolecular interaction with a CH_2 group. Analysis of the aromatic interactions in BOMRAY reveals strong face-face π-stacking interactions, albeit with an offset, meaning only one of the phenyl rings is involved in the interaction.

Table 3
Summary of the percentages of intermolecular contacts contributed to the HSA surface of Fmoc-protected β-aminobutyric acid **1**.

Inside atom	Outside atom				Total contributions
	C	H	N	O	
C	2.0	13.0	0.0	0.2	15.3
H	9.8	51.8	0.5	9.8	71.9
N	0.0	0.5	0.0	0.0	0.5
O	0.2	11.6	0.0	0.5	12.3
Total contributions	12.0	77.0	0.5	10.5	

Table 4
Summary of the percentages of intermolecular contacts contributed to the HSA surface of Fmoc carbamate **2**.

Inside atom	Outside atom				Total contributions
	C	H	N	O	
C	2.6	17.9	0.0	0.1	20.7
H	13.6	51.9	1.2	4.9	71.6
N	0.0	1.2	0.0	0.2	1.4
O	0.1	5.5	0.1	0.6	6.4
Total contributions	16.3	76.6	1.3	5.8	

5. Hirshfeld surface analysis

In order to visualise the intermolecular interactions in **1** and **2**, Hirshfeld surface analysis was carried out using *CrystalExplorer* 21.5 (Spackman *et al.*, 2021) and visualised *via* two-dimensional fingerprint plots (McKinnon *et al.*, 2007). The Hirshfeld surface analysis of **2** was carried out with the asymmetric unit of the two molecules. The left columns of Fig. 7 (top) and 8 (top) show the Hirshfeld surfaces of **1** and **2**, respectively, each mapped with the function d_{norm}, which is the

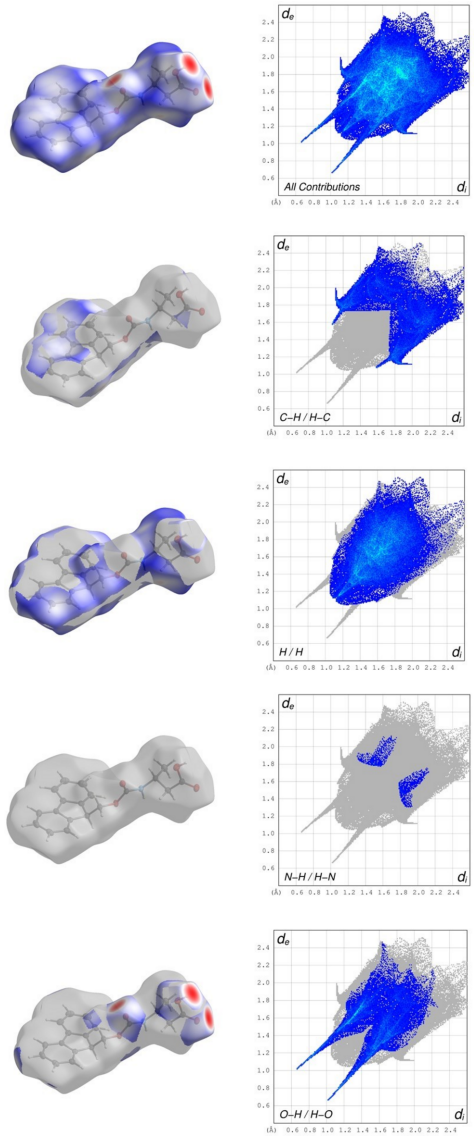

Figure 7
Hirshfeld surfaces of **1** mapped with d_{norm} (left image of each pair) with the corresponding two-dimensional fingerprint plot (right image of each pair) showing firstly all contributions and then the major contributions of C···H/H···C, H···H, N···H/H···N and O···H/H···O contacts.

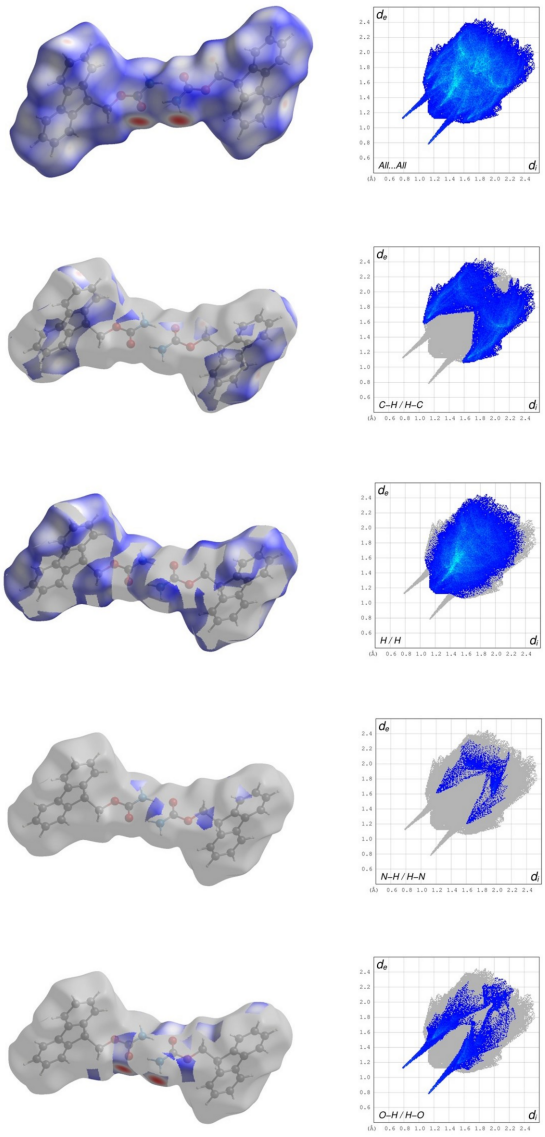

Figure 8
Hirshfeld surfaces of **2** mapped with d_{norm} (left image of each pair) with the corresponding two-dimensional fingerprint plot (right image of each pair) showing firstly all contributions and then the major contributions of C···H/H···C, H···H, N···H/H···N and O···H/H···O contacts.

sum of the distances from a surface point to the nearest interior (d_i) and exterior(d_e) atom, normalized by the van der Waals (vdW) radii of the corresponding atom (r_{vdW}). Contacts shorter than the sum of their vdW radii are shown in red, those longer in blue and those approximately equal to their vdW radii in white. In the structure of **1**, Fig. 7, the shortest contacts, with the most intense red spots, are shown to be the hydrogen-bonding sites, as shown in Fig. 4, the carboxylic acid and amide. The fingerprint plots (Tan *et al.*, 2019) for **1** and **2** are given in the right columns of Figs. 7 and 8 and the intermolecular interactions shown in Tables 3 and 4, respectively. The overall fingerprint plots are shown first (top) followed by those delineated into C···H/H···C, H/H, N···H/H···N and O···H/H···O. For **1**, the most important overall contribution is H···H, Fig. 7, contributing 51.8% with the tip of $d_e = d_i$ at 1.12 Å. The shortest interactions, the hydrogen bonding at the carboxylic acid and amide sites, as highlighted by the d_{norm} surface plot, are clearly visualized in the bottom O···H/H···O plot with the shortest distances. The C···H···π interactions are shown in the the surface of the C···H/H···C highlighted figure as well as the characteristic wings revealed in the fingerprint plot. For structure **2**, while the dimerization of the amine and carbonyl within the asymmetric unit is occluded from the view, the surface map shows the brightest red spots corresponding to the hydrogen bond formed from the amine to carbonyl, clearly highlighted in Fig. 8 (bottom) surface displaying O···H/H···O contacts and its corresponding plot demonstrating the shortest distance. In **2**, the most important contribution again is H···H, contributing 51.9% with the tip of $d_e = d_i$ at 1.16 Å.

6. Synthesis and crystallization

Fmoc-Cl was initially derivatized into Fmoc-N_3 to prepare it for addition to solutions of the β-amino acid. Specifically, 10 mmol of Fmoc-Cl were dissolved in dioxane (5 ml), while 12 mmol of NaN_3 were dissolved in a 2:1 mixture of dioxane/water (10 ml). The Fmoc-Cl solution was then added to the NaN_3 solution, and the resulting mixture was stirred at 323 K for 2 h.>

For the synthesis of **1**, (Fig. 9)11 mmol of R-βABA were dissolved in a 2:1 mixture of dioxane/10% $NaHCO_3$, which maintains the pH at 8–9. The Fmoc-N_3 solution was cautiously added in three portions to the β-amino acid over a period of 1 h. The reaction mixture was then stirred for 15 h at room temperature. Following the reaction, the mixture was poured into 5 mL of ice-cold water and subjected to three extractions with petroleum ether. The aqueous layers were separated using a separation funnel and chilled on ice for 2 h. Subsequently, the aqueous layer was acidified to pH 1 with 2 *M* HCl. The resulting precipitate was filtered and washed with ice-cold water until a pH of about 5 was attained. The collected white solid was placed in a petri dish covered with a paper towel and left to dry overnight within the fume hood. X-ray quality single crystals were grown by recrystallization from ethyl acetate/pet ether. **NMR**: ^{1}H NMR (400 MHz, DMSO) δ = 12.18 (*s*, 1H), 7.89 (*dd*, *J* = 7.3, 5.9, 3H), 7.73–7.62 (*m*, 3H), 7.47–7.26 (*m*, 7H), 4.63 (*d*, *J* = 6.2, 1H), 4.38–4.17 (*m*, 3H), 3.88 (*hept*, *J* = 6.8, 1H), 2.50–2.42 (*m*, 1H), 2.30 (*dd*, *J* = 15.4, 7.3, 1H), 1.10 (*d*, *J* = 6.6, 2H). ^{13}C NMR (101 MHz, DMSO) δ 128.03, 127.32, 125.56, 125.21, 120.29, 69.65, 65.78, 65.43, 47.14, 47.14, 46.44, 44.33, 41.51, 41.51, 41.16, 40.11, 21.12, 20.77. MP:120-125 °C HRMS Analysis: *m*/*z* (ES^+) 326.1401. $C_{19}H_{20}NO_4$ requires 326.1387.

For the synthesis of **2**, 11 mmol of DL-β-phenylalanine were dissolved in a 2:1 mixture of dioxane/10% $NaHCO_3$ along with NH_4OH (1 mL), which maintains the pH at 12. As above, the Fmoc-N_3 solution was cautiously added in three portions to the β-amino acid over a period of 1 h. The reaction mixture was then stirred for 15 h at room temperature. Following the reaction, the mixture was poured into 5 mL of ice-cold water and subjected to three extractions with petroleum ether. The aqueous layers were separated using a separation funnel and chilled on ice for 2 h. Subsequently, the aqueous layer was acidified to pH 1 with 2 *M* HCl. The resulting precipitate was filtered and washed with ice-cold water until a pH of about 5 was attained. The collected white solid was placed in a Petri dish covered with a paper towel and left to dry overnight within the fume hood. X-ray quality single crystals were grown by recrystallization from ethyl acetate/pet ether. M.p. 471–473 K NMR: ^{1}H NMR (400 MHz, DMSO) δ = 7.89 (*d*, *J* = 7.5, 2H), 7.70 (*d*, *J* = 7.4, 2H), 7.46–7.38 (*m*, 2H), 7.34 (*td*, *J* = 7.4, 1.2, 2H), 6.75 (*s*, 1H), 6.55 (*s*, 1H), 4.28 (*d*, *J* = 1.6, 1H), 4.27 (*s*, 1H), 4.22 (*dd*, *J* = 8.0, 5.7, 1H). ^{13}C NMR (101 MHz, DMSO) δ = 157.20, 157.13, 144.45, 143.05, 141.21, 139.90, 137.90, 129.39, 128.06, 127.76, 127.52, 125.62, 121.85, 120.57, 120.49, 110.19,

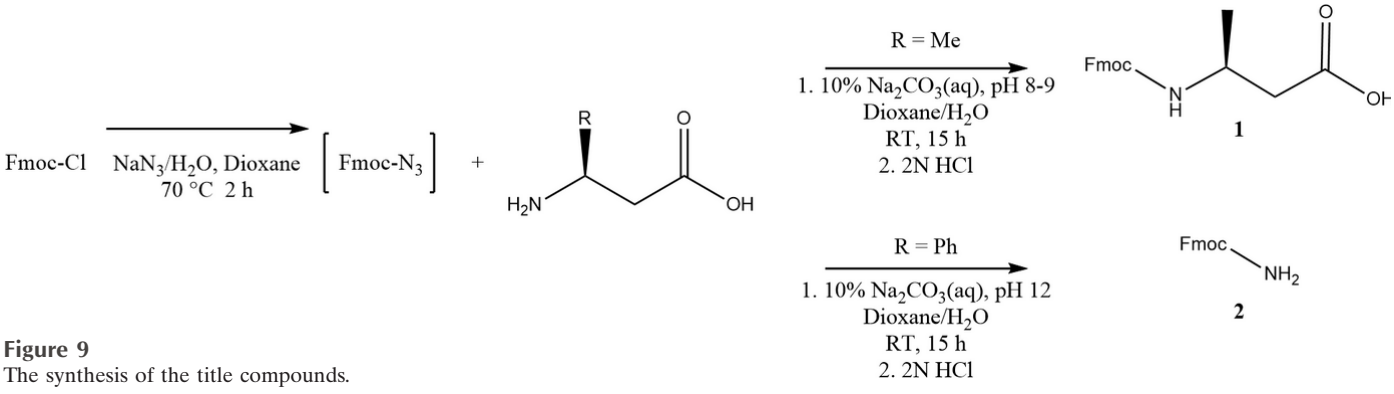

Figure 9
The synthesis of the title compounds.

Table 5
Experimental details.

	1	**2**
Crystal data		
Chemical formula	$C_{19}H_{19}NO_4$	$C_{15}H_{13}NO_2$
M_r	325.35	239.26
Crystal system, space group	Orthorhombic, $P2_12_12_1$	Orthorhombic, $Pca2_1$
Temperature (K)	100	100
a, b, c (Å)	4.8393 (2), 12.4928 (4), 27.3101 (9)	15.3560 (3), 5.0400 (1), 31.0254 (7)
V (Å^3)	1651.07 (10)	2401.19 (9)
Z	4	8
Radiation type	Cu $K\alpha$	Cu $K\alpha$
μ (mm^{-1})	0.75	0.71
Crystal size (mm)	0.3 × 0.03 × 0.01	0.25 × 0.03 × 0.01
Data collection		
Diffractometer	Bruker D8 Venture Photon III	Bruker D8 Venture Photon III
Absorption correction	Multi-scan (*SADABS*; Krause *et al.*, 2015)	Multi-scan (*SADABS*; Krause *et al.*, 2015)
T_{min}, T_{max}	0.664, 0.753	0.683, 0.753
No. of measured, independent and observed [$I > 2\sigma(I)$] reflections	25780, 2922, 2590	18874, 4069, 3754
R_{int}	0.081	0.051
(sin $\theta/\lambda)_{max}$ (Å^{-1})	0.596	0.596
Refinement		
$R[F^2 > 2\sigma(F^2)]$, $wR(F^2)$, S	0.032, 0.073, 1.06	0.030, 0.068, 1.05
No. of reflections	2922	4069
No. of parameters	226	341
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
$\Delta\rho_{max}$, $\Delta\rho_{min}$ (e Å^{-3})	0.12, −0.17	0.14, −0.17
Absolute structure	Flack x determined using 992 quotients $[(I^+)-(I^-)]/[(I^+)+(I^-)]$ (Parsons *et al.*, 2013)	Flack x determined using 1617 quotients $[(I^+)-(I^-)]/[(I^+)+(I^-)]$ (Parsons et al., 2013)
Absolute structure parameter	−0.05 (14)	−0.26 (13)

Computer programs: *APEX5* and *SAINT* V8.40B (Bruker, 2023), *SHELXT2018/2* (Sheldrick, 2015*a*), *SHELXL* (Sheldrick, 2015*b*) and *OLEX2* (Dolomanov *et al.*, 2009).

65.48, 47.22. HRMS Analysis: m/z (ES$^+$) $C_{15}H_{13}NO_2$ requires 239.26.

7. Refinement

Crystal data, data collection and structure refinement details are summarized in Table 5. All carbon-bound H atoms were positioned geometrically and refined as riding, with aromatic C—H = 0.95 Å, sp^3 C—H = 1.00 Å, sp^3 C—H_2 0.99 Å and with U_{iso}(H) = 1.2 U_{eq}(C) and sp^3 C—H_3 = 0.98 Å with U_{iso}(H) = 1.5U_{eq}(methyl C). Hydrogen atoms involved in hydrogen-bonding interactions were refined isotropically.

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supporting information

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Synthesis, crystal structure and Hirshfeld surface analysis of Fmoc-*β*-amino butyric acid and Fmoc carbamate

Mubarak Abubakar Magaji, Beining Chen and Craig Collumbine Robertson

Computing details

3-{[(9*H*-Fluoren-9-ylmethoxy)carbonyl]amino}butanoic acid (1)

Crystal data

$C_{19}H_{19}NO_4$
M_r = 325.35
Orthorhombic, $P2_12_12_1$
a = 4.8393 (2) Å
b = 12.4928 (4) Å
c = 27.3101 (9) Å
V = 1651.07 (10) Å^3
Z = 4
$F(000)$ = 688
D_x = 1.309 Mg m^{-3}
Cu $K\alpha$ radiation, λ = 1.54178 Å
Cell parameters from 3582 reflections
θ = 3.2–66.6°
μ = 0.75 mm^{-1}
T = 100 K
Needle, colourless
0.3 × 0.03 × 0.01 mm

Data collection

Bruker D8 Venture Photon III diffractometer
φ and ω scans
Absorption correction: multi-scan (SADABS; Krause *et al.*, 2015)
T_{min} = 0.664, T_{max} = 0.753
25780 measured reflections
2922 independent reflections
2590 reflections with $I > 2\sigma(I)$
R_{int} = 0.081
θ_{max} = 66.8°, θ_{min} = 3.2°
h = −5→5
k = −14→14
l = −32→31

Refinement

Refinement on F^2
Least-squares matrix: full
$R[F^2 > 2\sigma(F^2)]$ = 0.032
$wR(F^2)$ = 0.073
S = 1.06
2922 reflections
226 parameters
0 restraints
Primary atom site location: dual
Hydrogen site location: mixed
H atoms treated by a mixture of independent and constrained refinement
$w = 1/[\sigma^2(F_o^2) + (0.0304P)^2 + 0.2044P]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{max} < 0.001$
$\Delta\rho_{max}$ = 0.12 e Å^{-3}
$\Delta\rho_{min}$ = −0.17 e Å^{-3}
Absolute structure: Flack x determined using 992 quotients $[(I^+)-(I^-)]/[(I^+)+(I^-)]$ (Parsons *et al.*, 2013)
Absolute structure parameter: −0.05 (14)

Special details

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

Refinement. For **1**, a needle crystal with dimensions 0.01 x 0.026 x 0.3 mm was selected and for **2**, a needle crystal with dimensions 0.012 x 0.026 x 0.25 was selected. Intensity data for each was collected on a Bruker Venture Photon III diffractometer operating with a CuKα microfocus X-ray source with the crystal mounted in fomblin oil on a MicroMount (MiTeGen, USA) and cooled to 100 K in a stream of cold nitrogen gas using an Oxford Cryosystems 700 Cryostream. Data were corrected for absorption using empirical methods (SADABS; Bruker, 2023) based upon symmetry equivalent reflections combined with measurements at different azimuthal angles (Krause *et al.*, 2015). The crystal structures were solved and refined against F^2 values using ShelXT (Sheldrick, 2015a) for solution and ShelXL (Sheldrick, 2015b) for refinement accessed *via* the Olex2 program (Dolomanov *et al.*, 2009). Non-hydrogen atoms were refined anisotropically.

Fractional atomic coordinates and isotropic or equivalent isotropic displacement parameters (Å²)

	x	*y*	*z*	U_{iso}*/U_{eq}
O1	0.6114 (3)	0.65660 (13)	0.60381 (6)	0.0260 (4)
O2	0.2958 (3)	0.76326 (12)	0.64093 (6)	0.0254 (4)
O3	−0.0146 (4)	0.30716 (13)	0.53156 (6)	0.0309 (4)
O4	0.3887 (4)	0.38097 (14)	0.51041 (7)	0.0331 (4)
H4	0.422 (8)	0.314 (3)	0.4965 (14)	0.078 (12)*
N1	0.1735 (4)	0.67252 (15)	0.57425 (7)	0.0215 (4)
H1	0.005 (6)	0.691 (2)	0.5827 (9)	0.032 (7)*
C1	0.4148 (5)	0.89471 (18)	0.70131 (8)	0.0230 (5)
H1A	0.227847	0.885997	0.716402	0.028*
C2	0.4183 (5)	0.99043 (18)	0.66703 (8)	0.0231 (5)
C3	0.2681 (5)	1.0088 (2)	0.62449 (9)	0.0309 (6)
H3	0.133824	0.958606	0.613666	0.037*
C4	0.3181 (6)	1.1019 (2)	0.59806 (10)	0.0372 (7)
H4A	0.216012	1.115393	0.568994	0.045*
C5	0.5141 (6)	1.1755 (2)	0.61339 (10)	0.0374 (7)
H5	0.546508	1.238106	0.594522	0.045*
C6	0.6638 (6)	1.15843 (19)	0.65610 (10)	0.0326 (6)
H6	0.797817	1.208928	0.666704	0.039*
C7	0.6136 (5)	1.06620 (19)	0.68294 (9)	0.0250 (5)
C8	0.7377 (5)	1.02758 (18)	0.72875 (9)	0.0239 (5)
C9	0.9348 (5)	1.0736 (2)	0.75932 (10)	0.0304 (6)
H9	1.010016	1.142041	0.751993	0.037*
C10	1.0195 (6)	1.0182 (2)	0.80057 (9)	0.0346 (6)
H10	1.151438	1.049315	0.822029	0.042*
C11	0.9134 (6)	0.9177 (2)	0.81081 (9)	0.0322 (6)
H11	0.977890	0.879868	0.838730	0.039*
C12	0.7136 (5)	0.8712 (2)	0.78084 (9)	0.0273 (6)
H12	0.639459	0.802678	0.788335	0.033*
C13	0.6254 (5)	0.92702 (18)	0.73987 (8)	0.0229 (5)
C14	0.5056 (5)	0.79107 (19)	0.67675 (9)	0.0249 (5)
H14A	0.686512	0.801056	0.660463	0.030*
H14B	0.523900	0.733348	0.701367	0.030*

C15	0.3773 (5)	0.69342 (17)	0.60606 (9)	0.0213 (5)
C16	0.2032 (5)	0.58643 (17)	0.53839 (8)	0.0212 (5)
H16	0.404379	0.576644	0.531365	0.025*
C17	0.0920 (5)	0.48249 (18)	0.56036 (9)	0.0255 (5)
H17A	0.172825	0.473954	0.593435	0.031*
H17B	−0.110285	0.490126	0.564482	0.031*
C18	0.1454 (5)	0.38223 (18)	0.53224 (9)	0.0230 (5)
C19	0.0586 (6)	0.6161 (2)	0.49085 (9)	0.0314 (6)
H19A	−0.139338	0.625852	0.497011	0.047*
H19B	0.084998	0.558750	0.466822	0.047*
H19C	0.136876	0.682848	0.478078	0.047*

Atomic displacement parameters (Å²)

	U^{11}	U^{22}	U^{33}	U^{12}	U^{13}	U^{23}
O1	0.0159 (8)	0.0299 (9)	0.0323 (9)	0.0033 (7)	−0.0010 (7)	−0.0065 (8)
O2	0.0174 (8)	0.0265 (8)	0.0322 (9)	0.0008 (7)	−0.0031 (7)	−0.0098 (7)
O3	0.0281 (9)	0.0220 (8)	0.0427 (11)	−0.0025 (7)	0.0001 (8)	−0.0051 (8)
O4	0.0280 (10)	0.0227 (9)	0.0486 (12)	0.0002 (8)	0.0117 (9)	−0.0072 (8)
N1	0.0147 (10)	0.0212 (10)	0.0287 (11)	0.0010 (8)	−0.0011 (9)	−0.0044 (9)
C1	0.0195 (12)	0.0233 (12)	0.0263 (13)	−0.0004 (10)	−0.0001 (10)	−0.0031 (10)
C2	0.0202 (12)	0.0246 (12)	0.0246 (12)	0.0042 (10)	0.0031 (10)	−0.0036 (10)
C3	0.0278 (14)	0.0346 (14)	0.0304 (13)	0.0074 (12)	−0.0007 (11)	−0.0066 (12)
C4	0.0404 (16)	0.0419 (16)	0.0292 (14)	0.0167 (14)	−0.0002 (12)	0.0046 (12)
C5	0.0420 (16)	0.0315 (15)	0.0385 (16)	0.0098 (13)	0.0110 (13)	0.0094 (12)
C6	0.0316 (15)	0.0262 (13)	0.0402 (15)	0.0026 (12)	0.0074 (12)	0.0010 (12)
C7	0.0225 (12)	0.0235 (12)	0.0290 (13)	0.0040 (10)	0.0045 (10)	−0.0028 (10)
C8	0.0212 (12)	0.0236 (12)	0.0267 (13)	0.0007 (10)	0.0029 (10)	−0.0059 (10)
C9	0.0253 (14)	0.0266 (13)	0.0394 (15)	−0.0021 (11)	0.0021 (11)	−0.0098 (12)
C10	0.0307 (14)	0.0397 (16)	0.0336 (15)	0.0050 (12)	−0.0056 (12)	−0.0159 (13)
C11	0.0351 (15)	0.0360 (14)	0.0254 (13)	0.0116 (12)	−0.0032 (11)	−0.0072 (11)
C12	0.0311 (14)	0.0249 (12)	0.0258 (13)	0.0037 (11)	0.0039 (11)	−0.0036 (10)
C13	0.0204 (12)	0.0239 (12)	0.0243 (12)	0.0014 (10)	0.0038 (10)	−0.0044 (10)
C14	0.0199 (12)	0.0268 (13)	0.0279 (13)	−0.0010 (10)	−0.0042 (10)	−0.0063 (11)
C15	0.0209 (12)	0.0179 (11)	0.0251 (12)	−0.0031 (10)	0.0011 (10)	−0.0005 (10)
C16	0.0175 (11)	0.0203 (11)	0.0258 (12)	−0.0001 (9)	−0.0011 (10)	−0.0032 (10)
C17	0.0269 (12)	0.0220 (12)	0.0276 (13)	−0.0005 (10)	0.0043 (10)	−0.0026 (10)
C18	0.0222 (13)	0.0206 (11)	0.0261 (13)	0.0003 (10)	−0.0025 (10)	0.0025 (10)
C19	0.0382 (16)	0.0261 (13)	0.0300 (14)	0.0002 (12)	−0.0060 (12)	−0.0010 (11)

Geometric parameters (Å, º)

O1—C15	1.224 (3)	C7—C8	1.469 (3)
O2—C14	1.452 (3)	C8—C9	1.392 (3)
O2—C15	1.350 (3)	C8—C13	1.402 (3)
O3—C18	1.216 (3)	C9—H9	0.9500
O4—H4	0.94 (4)	C9—C10	1.385 (4)
O4—C18	1.320 (3)	C10—H10	0.9500

N1—H1	0.88 (3)	C10—C11	1.384 (4)
N1—C15	1.340 (3)	C11—H11	0.9500
N1—C16	1.462 (3)	C11—C12	1.394 (4)
C1—H1A	1.0000	C12—H12	0.9500
C1—C2	1.519 (3)	C12—C13	1.386 (3)
C1—C13	1.520 (3)	C14—H14A	0.9900
C1—C14	1.523 (3)	C14—H14B	0.9900
C2—C3	1.389 (3)	C16—H16	1.0000
C2—C7	1.407 (3)	C16—C17	1.528 (3)
C3—H3	0.9500	C16—C19	1.521 (3)
C3—C4	1.391 (4)	C17—H17A	0.9900
C4—H4A	0.9500	C17—H17B	0.9900
C4—C5	1.385 (4)	C17—C18	1.492 (3)
C5—H5	0.9500	C19—H19A	0.9800
C5—C6	1.390 (4)	C19—H19B	0.9800
C6—H6	0.9500	C19—H19C	0.9800
C6—C7	1.387 (3)		

C15—O2—C14	115.19 (17)	C10—C11—C12	121.1 (2)
C18—O4—H4	110 (2)	C12—C11—H11	119.4
C15—N1—H1	117.4 (18)	C11—C12—H12	120.7
C15—N1—C16	120.36 (19)	C13—C12—C11	118.5 (2)
C16—N1—H1	117.6 (18)	C13—C12—H12	120.7
C2—C1—H1A	110.5	C8—C13—C1	110.4 (2)
C2—C1—C13	102.15 (19)	C12—C13—C1	129.2 (2)
C2—C1—C14	113.24 (19)	C12—C13—C8	120.4 (2)
C13—C1—H1A	110.5	O2—C14—C1	107.37 (19)
C13—C1—C14	109.72 (19)	O2—C14—H14A	110.2
C14—C1—H1A	110.5	O2—C14—H14B	110.2
C3—C2—C1	129.7 (2)	C1—C14—H14A	110.2
C3—C2—C7	119.9 (2)	C1—C14—H14B	110.2
C7—C2—C1	110.3 (2)	H14A—C14—H14B	108.5
C2—C3—H3	120.6	O1—C15—O2	123.3 (2)
C2—C3—C4	118.8 (3)	O1—C15—N1	125.1 (2)
C4—C3—H3	120.6	N1—C15—O2	111.6 (2)
C3—C4—H4A	119.4	N1—C16—H16	108.3
C5—C4—C3	121.1 (3)	N1—C16—C17	109.11 (19)
C5—C4—H4A	119.4	N1—C16—C19	110.34 (18)
C4—C5—H5	119.7	C17—C16—H16	108.3
C4—C5—C6	120.6 (3)	C19—C16—H16	108.3
C6—C5—H5	119.7	C19—C16—C17	112.4 (2)
C5—C6—H6	120.7	C16—C17—H17A	108.1
C7—C6—C5	118.7 (3)	C16—C17—H17B	108.1
C7—C6—H6	120.7	H17A—C17—H17B	107.3
C2—C7—C8	108.5 (2)	C18—C17—C16	116.76 (19)
C6—C7—C2	120.9 (2)	C18—C17—H17A	108.1
C6—C7—C8	130.6 (2)	C18—C17—H17B	108.1
C9—C8—C7	130.9 (2)	O3—C18—O4	123.5 (2)

C9—C8—C13	120.4 (2)	O3—C18—C17	123.0 (2)
C13—C8—C7	108.7 (2)	O4—C18—C17	113.4 (2)
C8—C9—H9	120.5	C16—C19—H19A	109.5
C10—C9—C8	118.9 (2)	C16—C19—H19B	109.5
C10—C9—H9	120.5	C16—C19—H19C	109.5
C9—C10—H10	119.7	H19A—C19—H19B	109.5
C11—C10—C9	120.5 (2)	H19A—C19—H19C	109.5
C11—C10—H10	119.7	H19B—C19—H19C	109.5
C10—C11—H11	119.4		

N1—C16—C17—C18	−170.6 (2)	C9—C8—C13—C12	−1.4 (3)
C1—C2—C3—C4	−177.1 (2)	C9—C10—C11—C12	−1.9 (4)
C1—C2—C7—C6	176.9 (2)	C10—C11—C12—C13	1.0 (4)
C1—C2—C7—C8	−2.4 (3)	C11—C12—C13—C1	179.4 (2)
C2—C1—C13—C8	−0.7 (2)	C11—C12—C13—C8	0.7 (3)
C2—C1—C13—C12	−179.5 (2)	C13—C1—C2—C3	−179.9 (2)
C2—C1—C14—O2	−67.4 (3)	C13—C1—C2—C7	1.9 (2)
C2—C3—C4—C5	0.2 (4)	C13—C1—C14—O2	179.18 (18)
C2—C7—C8—C9	−178.4 (2)	C13—C8—C9—C10	0.5 (4)
C2—C7—C8—C13	1.9 (3)	C14—O2—C15—O1	−1.0 (3)
C3—C2—C7—C6	−1.5 (4)	C14—O2—C15—N1	−179.49 (19)
C3—C2—C7—C8	179.2 (2)	C14—C1—C2—C3	62.2 (3)
C3—C4—C5—C6	−0.8 (4)	C14—C1—C2—C7	−116.0 (2)
C4—C5—C6—C7	0.2 (4)	C14—C1—C13—C8	119.7 (2)
C5—C6—C7—C2	0.9 (4)	C14—C1—C13—C12	−59.1 (3)
C5—C6—C7—C8	−179.9 (2)	C15—O2—C14—C1	161.10 (18)
C6—C7—C8—C9	2.3 (4)	C15—N1—C16—C17	90.3 (3)
C6—C7—C8—C13	−177.3 (3)	C15—N1—C16—C19	−145.8 (2)
C7—C2—C3—C4	0.9 (4)	C16—N1—C15—O1	11.4 (4)
C7—C8—C9—C10	−179.0 (2)	C16—N1—C15—O2	−170.19 (18)
C7—C8—C13—C1	−0.7 (3)	C16—C17—C18—O3	−147.0 (2)
C7—C8—C13—C12	178.2 (2)	C16—C17—C18—O4	36.3 (3)
C8—C9—C10—C11	1.1 (4)	C19—C16—C17—C18	66.7 (3)
C9—C8—C13—C1	179.6 (2)		

Hydrogen-bond geometry (Å, º)

D—H···*A*	*D*—H	H···*A*	*D*···*A*	*D*—H···*A*
O4—H4···O3^{i}	0.94 (4)	1.72 (4)	2.656 (2)	177 (3)
N1—H1···O1^{ii}	0.88 (3)	2.04 (3)	2.844 (3)	152 (2)

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

(2)

Crystal data

$C_{15}H_{13}NO_2$	*a* = 15.3560 (3) Å
M_r = 239.26	*b* = 5.0400 (1) Å
Orthorhombic, $Pca2_1$	*c* = 31.0254 (7) Å

V = 2401.19 (9) Å^3
Z = 8
F(000) = 1008
D_x = 1.324 Mg m^{-3}
Cu $K\alpha$ radiation, λ = 1.54178 Å
Cell parameters from 6701 reflections

θ = 3.2–65.9°
μ = 0.71 mm^{-1}
T = 100 K
Needle, colourless
0.25 × 0.03 × 0.01 mm

Data collection

Bruker D8 Venture Photon III diffractometer
φ and ω scans
Absorption correction: multi-scan (SADABS; Krause *et al.*, 2015)
T_{min} = 0.683, T_{max} = 0.753
18874 measured reflections

4069 independent reflections
3754 reflections with $I > 2\sigma(I)$
R_{int} = 0.051
θ_{max} = 66.8°, θ_{min} = 2.9°
h = −18→18
k = −5→5
l = −36→36

Refinement

Refinement on F^2
Least-squares matrix: full
$R[F^2 > 2\sigma(F^2)]$ = 0.030
$wR(F^2)$ = 0.068
S = 1.05
4069 reflections
341 parameters
1 restraint
Primary atom site location: dual
Hydrogen site location: mixed

H atoms treated by a mixture of independent and constrained refinement
$w = 1/[\sigma^2(F_o^2) + (0.0291P)^2 + 0.3089P]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{max} < 0.001$
$\Delta\rho_{max}$ = 0.14 e Å^{-3}
$\Delta\rho_{min}$ = −0.16 e Å^{-3}
Absolute structure: Flack x determined using 1617 quotients $[(I^+)-(I^-)]/[(I^+)+(I^-)]$ (Parsons et al., 2013)
Absolute structure parameter: −0.26 (13)

Special details

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

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

	x	y	z	U_{iso}*/U_{eq}
O1	0.53087 (12)	0.7151 (3)	0.47451 (7)	0.0233 (4)
O2	0.42477 (11)	0.4384 (3)	0.45115 (6)	0.0198 (4)
N1	0.53609 (17)	0.2741 (4)	0.48787 (8)	0.0230 (5)
H1A	0.5141 (19)	0.123 (6)	0.4816 (10)	0.019 (7)*
H1B	0.589 (2)	0.295 (6)	0.5007 (11)	0.031 (8)*
C1	0.32636 (17)	0.5633 (5)	0.39449 (9)	0.0176 (6)
H1	0.293372	0.398198	0.401756	0.021*
C2	0.26475 (15)	0.7768 (5)	0.37850 (9)	0.0176 (5)
C3	0.19497 (17)	0.8955 (5)	0.39955 (9)	0.0226 (6)
H3	0.179526	0.844026	0.427999	0.027*
C4	0.14832 (17)	1.0913 (6)	0.37805 (11)	0.0263 (6)
H4	0.100259	1.173510	0.391963	0.032*
C5	0.17085 (18)	1.1689 (5)	0.33649 (9)	0.0248 (6)
H5	0.138392	1.303942	0.322415	0.030*
C6	0.24063 (19)	1.0499 (5)	0.31541 (10)	0.0221 (6)

H6	0.256156	1.102689	0.287037	0.027*
C7	0.28718 (16)	0.8528 (5)	0.33653 (9)	0.0176 (5)
C8	0.36178 (15)	0.6916 (5)	0.32254 (8)	0.0171 (5)
C9	0.40625 (17)	0.6884 (5)	0.28345 (9)	0.0212 (6)
H9	0.391122	0.808222	0.261028	0.025*
C10	0.4733 (2)	0.5061 (5)	0.27793 (11)	0.0251 (7)
H10	0.503783	0.499597	0.251306	0.030*
C11	0.49616 (17)	0.3337 (5)	0.31090 (10)	0.0237 (6)
H11	0.542294	0.210925	0.306624	0.028*
C12	0.45228 (17)	0.3385 (5)	0.35021 (9)	0.0205 (6)
H12	0.468555	0.221720	0.372863	0.025*
C13	0.38445 (19)	0.5168 (5)	0.35564 (10)	0.0170 (6)
C14	0.37677 (17)	0.6619 (5)	0.43372 (9)	0.0194 (5)
H14A	0.417409	0.805151	0.425237	0.023*
H14B	0.336087	0.732822	0.455632	0.023*
C15	0.50003 (18)	0.4899 (5)	0.47137 (9)	0.0165 (6)
O3	0.71790 (12)	0.3289 (3)	0.51774 (6)	0.0235 (4)
O4	0.81702 (12)	0.6052 (3)	0.54788 (6)	0.0203 (4)
N2	0.71138 (16)	0.7720 (4)	0.50730 (8)	0.0201 (5)
H2A	0.663 (2)	0.759 (5)	0.4946 (10)	0.019 (7)*
H2B	0.730 (2)	0.928 (7)	0.5147 (11)	0.033 (9)*
C16	0.91776 (18)	0.4654 (5)	0.60216 (9)	0.0182 (6)
H16	0.948852	0.635510	0.595949	0.022*
C17	0.98232 (16)	0.2503 (5)	0.61506 (9)	0.0187 (5)
C18	1.05075 (16)	0.1434 (5)	0.59156 (9)	0.0229 (6)
H18	1.062974	0.204782	0.563253	0.028*
C19	1.10103 (18)	−0.0548 (6)	0.61018 (11)	0.0282 (7)
H19	1.148311	−0.128562	0.594474	0.034*
C20	1.08324 (19)	−0.1464 (5)	0.65126 (11)	0.0300 (7)
H20	1.118190	−0.283160	0.663310	0.036*
C21	1.0147 (2)	−0.0408 (5)	0.67526 (10)	0.0248 (7)
H21	1.002632	−0.103184	0.703529	0.030*
C22	0.96431 (16)	0.1588 (5)	0.65662 (9)	0.0187 (5)
C23	0.88995 (16)	0.3076 (5)	0.67375 (8)	0.0183 (5)
C24	0.84808 (18)	0.2916 (6)	0.71340 (9)	0.0232 (6)
H24	0.865756	0.164739	0.734293	0.028*
C25	0.7798 (2)	0.4652 (6)	0.72182 (11)	0.0274 (7)
H25	0.751130	0.458980	0.748942	0.033*
C26	0.75307 (19)	0.6472 (5)	0.69102 (10)	0.0266 (6)
H26	0.706041	0.763484	0.697254	0.032*
C27	0.79414 (17)	0.6619 (5)	0.65113 (9)	0.0225 (6)
H27	0.775450	0.786606	0.630113	0.027*
C28	0.86269 (19)	0.4917 (5)	0.64261 (10)	0.0178 (6)
C29	0.86563 (17)	0.3768 (5)	0.56314 (9)	0.0186 (5)
H29A	0.905150	0.311282	0.540284	0.022*
H29B	0.825305	0.231754	0.571180	0.022*
C30	0.74632 (18)	0.5541 (5)	0.52380 (9)	0.0164 (5)

Atomic displacement parameters (Å²)

	U^{11}	U^{22}	U^{33}	U^{12}	U^{13}	U^{23}
O1	0.0227 (10)	0.0147 (9)	0.0326 (11)	−0.0011 (7)	−0.0087 (8)	−0.0015 (8)
O2	0.0215 (10)	0.0167 (9)	0.0211 (10)	−0.0041 (7)	−0.0075 (8)	0.0043 (7)
N1	0.0222 (13)	0.0150 (12)	0.0318 (14)	−0.0029 (9)	−0.0085 (11)	0.0005 (10)
C1	0.0160 (14)	0.0192 (13)	0.0176 (14)	−0.0019 (11)	−0.0010 (11)	0.0023 (10)
C2	0.0145 (11)	0.0163 (12)	0.0220 (14)	−0.0035 (9)	−0.0055 (10)	−0.0027 (11)
C3	0.0177 (13)	0.0271 (14)	0.0231 (15)	−0.0014 (11)	−0.0005 (11)	−0.0039 (11)
C4	0.0146 (13)	0.0256 (14)	0.0388 (18)	0.0021 (11)	−0.0022 (12)	−0.0103 (14)
C5	0.0194 (13)	0.0216 (13)	0.0334 (16)	0.0018 (10)	−0.0108 (11)	−0.0008 (11)
C6	0.0236 (15)	0.0216 (13)	0.0212 (15)	−0.0006 (11)	−0.0047 (12)	0.0012 (11)
C7	0.0135 (12)	0.0169 (13)	0.0225 (14)	−0.0027 (9)	−0.0037 (10)	−0.0020 (10)
C8	0.0145 (12)	0.0159 (13)	0.0208 (14)	−0.0041 (10)	−0.0024 (10)	0.0004 (10)
C9	0.0209 (13)	0.0214 (13)	0.0213 (14)	−0.0013 (11)	0.0002 (11)	0.0037 (10)
C10	0.0197 (16)	0.0308 (16)	0.0248 (18)	−0.0006 (10)	0.0063 (13)	−0.0013 (12)
C11	0.0180 (13)	0.0226 (14)	0.0304 (16)	0.0019 (11)	0.0001 (11)	−0.0014 (11)
C12	0.0192 (13)	0.0186 (13)	0.0235 (15)	−0.0011 (10)	−0.0038 (11)	0.0018 (11)
C13	0.0157 (15)	0.0160 (13)	0.0194 (15)	−0.0034 (9)	−0.0047 (12)	−0.0014 (10)
C14	0.0200 (13)	0.0183 (13)	0.0199 (14)	0.0007 (9)	−0.0044 (11)	0.0033 (11)
C15	0.0160 (13)	0.0188 (13)	0.0149 (14)	0.0002 (9)	0.0005 (11)	−0.0020 (10)
O3	0.0211 (10)	0.0142 (9)	0.0351 (12)	−0.0008 (7)	−0.0083 (8)	−0.0002 (8)
O4	0.0226 (10)	0.0144 (9)	0.0239 (10)	−0.0017 (7)	−0.0079 (8)	0.0020 (8)
N2	0.0195 (12)	0.0145 (11)	0.0263 (13)	−0.0004 (9)	−0.0079 (10)	0.0012 (9)
C16	0.0163 (12)	0.0185 (13)	0.0198 (15)	−0.0012 (9)	−0.0030 (11)	0.0020 (11)
C17	0.0150 (11)	0.0190 (12)	0.0223 (14)	−0.0031 (9)	−0.0043 (10)	−0.0002 (10)
C18	0.0163 (12)	0.0278 (14)	0.0248 (15)	−0.0030 (10)	−0.0019 (11)	−0.0032 (11)
C19	0.0163 (14)	0.0311 (15)	0.0372 (18)	0.0008 (11)	−0.0036 (12)	−0.0071 (13)
C20	0.0256 (14)	0.0213 (14)	0.0432 (19)	0.0054 (11)	−0.0156 (14)	−0.0015 (12)
C21	0.0239 (16)	0.0251 (14)	0.0255 (16)	−0.0028 (11)	−0.0117 (13)	0.0028 (12)
C22	0.0183 (13)	0.0172 (12)	0.0205 (14)	−0.0033 (9)	−0.0056 (11)	−0.0008 (10)
C23	0.0183 (12)	0.0190 (13)	0.0176 (14)	−0.0053 (10)	−0.0044 (10)	0.0000 (10)
C24	0.0260 (14)	0.0268 (15)	0.0167 (13)	−0.0093 (11)	−0.0030 (10)	−0.0014 (11)
C25	0.0258 (17)	0.0327 (16)	0.0236 (18)	−0.0113 (12)	0.0054 (14)	−0.0104 (12)
C26	0.0208 (13)	0.0251 (15)	0.0340 (17)	−0.0021 (11)	0.0041 (12)	−0.0124 (12)
C27	0.0197 (13)	0.0202 (13)	0.0275 (15)	−0.0009 (10)	−0.0020 (12)	−0.0033 (11)
C28	0.0147 (14)	0.0186 (14)	0.0201 (16)	−0.0043 (9)	−0.0015 (12)	−0.0022 (10)
C29	0.0202 (13)	0.0166 (13)	0.0189 (13)	0.0030 (10)	−0.0025 (10)	0.0028 (10)
C30	0.0153 (13)	0.0197 (13)	0.0142 (14)	−0.0006 (10)	−0.0003 (11)	−0.0004 (11)

Geometric parameters (Å, º)

O1—C15	1.234 (3)	O3—C30	1.230 (3)
O2—C14	1.450 (3)	O4—C29	1.451 (3)
O2—C15	1.340 (3)	O4—C30	1.343 (3)
N1—H1A	0.86 (3)	N2—H2A	0.85 (3)
N1—H1B	0.91 (3)	N2—H2B	0.87 (4)
N1—C15	1.323 (4)	N2—C30	1.325 (3)

C1—H1	1.0000	C16—H16	1.0000
C1—C2	1.516 (4)	C16—C17	1.523 (4)
C1—C13	1.518 (4)	C16—C28	1.519 (4)
C1—C14	1.526 (4)	C16—C29	1.518 (4)
C2—C3	1.390 (4)	C17—C18	1.388 (4)
C2—C7	1.400 (4)	C17—C22	1.397 (4)
C3—H3	0.9500	C18—H18	0.9500
C3—C4	1.390 (4)	C18—C19	1.389 (4)
C4—H4	0.9500	C19—H19	0.9500
C4—C5	1.391 (4)	C19—C20	1.383 (5)
C5—H5	0.9500	C20—H20	0.9500
C5—C6	1.391 (4)	C20—C21	1.395 (4)
C6—H6	0.9500	C21—H21	0.9500
C6—C7	1.388 (4)	C21—C22	1.395 (4)
C7—C8	1.470 (4)	C22—C23	1.466 (4)
C8—C9	1.392 (4)	C23—C24	1.390 (4)
C8—C13	1.397 (4)	C23—C28	1.403 (4)
C9—H9	0.9500	C24—H24	0.9500
C9—C10	1.391 (4)	C24—C25	1.391 (4)
C10—H10	0.9500	C25—H25	0.9500
C10—C11	1.387 (4)	C25—C26	1.387 (5)
C11—H11	0.9500	C26—H26	0.9500
C11—C12	1.394 (4)	C26—C27	1.391 (4)
C12—H12	0.9500	C27—H27	0.9500
C12—C13	1.386 (4)	C27—C28	1.383 (4)
C14—H14A	0.9900	C29—H29A	0.9900
C14—H14B	0.9900	C29—H29B	0.9900

C15—O2—C14	117.54 (19)	C30—O4—C29	116.43 (19)
H1A—N1—H1B	124 (3)	H2A—N2—H2B	119 (3)
C15—N1—H1A	119 (2)	C30—N2—H2A	118.4 (19)
C15—N1—H1B	116 (2)	C30—N2—H2B	121 (2)
C2—C1—H1	110.4	C17—C16—H16	110.5
C2—C1—C13	102.5 (2)	C28—C16—H16	110.5
C2—C1—C14	110.3 (2)	C28—C16—C17	102.0 (2)
C13—C1—H1	110.4	C29—C16—H16	110.5
C13—C1—C14	112.7 (2)	C29—C16—C17	110.1 (2)
C14—C1—H1	110.4	C29—C16—C28	113.0 (2)
C3—C2—C1	129.3 (3)	C18—C17—C16	129.1 (2)
C3—C2—C7	120.6 (2)	C18—C17—C22	120.4 (2)
C7—C2—C1	110.2 (2)	C22—C17—C16	110.4 (2)
C2—C3—H3	120.7	C17—C18—H18	120.6
C4—C3—C2	118.5 (3)	C17—C18—C19	118.8 (3)
C4—C3—H3	120.7	C19—C18—H18	120.6
C3—C4—H4	119.5	C18—C19—H19	119.5
C3—C4—C5	121.1 (3)	C20—C19—C18	120.9 (3)
C5—C4—H4	119.5	C20—C19—H19	119.5
C4—C5—H5	119.8	C19—C20—H20	119.6

C4—C5—C6	120.4 (3)	C19—C20—C21	120.9 (3)
C6—C5—H5	119.8	C21—C20—H20	119.6
C5—C6—H6	120.6	C20—C21—H21	120.9
C7—C6—C5	118.9 (3)	C22—C21—C20	118.2 (3)
C7—C6—H6	120.6	C22—C21—H21	120.9
C2—C7—C8	108.4 (2)	C17—C22—C23	108.7 (2)
C6—C7—C2	120.5 (2)	C21—C22—C17	120.7 (3)
C6—C7—C8	131.1 (3)	C21—C22—C23	130.6 (3)
C9—C8—C7	130.2 (2)	C24—C23—C22	130.6 (2)
C9—C8—C13	120.7 (2)	C24—C23—C28	120.6 (2)
C13—C8—C7	109.0 (2)	C28—C23—C22	108.7 (2)
C8—C9—H9	120.7	C23—C24—H24	120.7
C10—C9—C8	118.6 (3)	C23—C24—C25	118.6 (3)
C10—C9—H9	120.7	C25—C24—H24	120.7
C9—C10—H10	119.7	C24—C25—H25	119.7
C11—C10—C9	120.7 (3)	C26—C25—C24	120.7 (3)
C11—C10—H10	119.7	C26—C25—H25	119.7
C10—C11—H11	119.6	C25—C26—H26	119.5
C10—C11—C12	120.8 (2)	C25—C26—C27	121.0 (3)
C12—C11—H11	119.6	C27—C26—H26	119.5
C11—C12—H12	120.6	C26—C27—H27	120.6
C13—C12—C11	118.7 (3)	C28—C27—C26	118.8 (3)
C13—C12—H12	120.6	C28—C27—H27	120.6
C8—C13—C1	109.9 (2)	C23—C28—C16	110.2 (2)
C12—C13—C1	129.7 (3)	C27—C28—C16	129.5 (3)
C12—C13—C8	120.4 (3)	C27—C28—C23	120.4 (3)
O2—C14—C1	107.6 (2)	O4—C29—C16	107.33 (19)
O2—C14—H14A	110.2	O4—C29—H29A	110.2
O2—C14—H14B	110.2	O4—C29—H29B	110.2
C1—C14—H14A	110.2	C16—C29—H29A	110.2
C1—C14—H14B	110.2	C16—C29—H29B	110.2
H14A—C14—H14B	108.5	H29A—C29—H29B	108.5
O1—C15—O2	123.1 (2)	O3—C30—O4	123.3 (2)
O1—C15—N1	124.4 (3)	O3—C30—N2	124.2 (3)
N1—C15—O2	112.5 (2)	N2—C30—O4	112.5 (2)

C1—C2—C3—C4	179.2 (3)	C16—C17—C18—C19	−179.5 (3)
C1—C2—C7—C6	−178.9 (2)	C16—C17—C22—C21	179.5 (2)
C1—C2—C7—C8	1.5 (3)	C16—C17—C22—C23	−1.2 (3)
C2—C1—C13—C8	2.8 (3)	C17—C16—C28—C23	−2.3 (3)
C2—C1—C13—C12	−178.2 (3)	C17—C16—C28—C27	178.2 (3)
C2—C1—C14—O2	171.9 (2)	C17—C16—C29—O4	−170.1 (2)
C2—C3—C4—C5	−0.4 (4)	C17—C18—C19—C20	0.4 (4)
C2—C7—C8—C9	178.4 (2)	C17—C22—C23—C24	−179.6 (2)
C2—C7—C8—C13	0.4 (3)	C17—C22—C23—C28	−0.3 (3)
C3—C2—C7—C6	0.6 (4)	C18—C17—C22—C21	0.1 (4)
C3—C2—C7—C8	−179.0 (2)	C18—C17—C22—C23	179.4 (2)
C3—C4—C5—C6	0.4 (4)	C18—C19—C20—C21	−0.5 (4)

C4—C5—C6—C7	0.1 (4)	C19—C20—C21—C22	0.3 (4)
C5—C6—C7—C2	−0.6 (4)	C20—C21—C22—C17	−0.1 (4)
C5—C6—C7—C8	179.0 (3)	C20—C21—C22—C23	−179.2 (3)
C6—C7—C8—C9	−1.2 (5)	C21—C22—C23—C24	−0.3 (5)
C6—C7—C8—C13	−179.2 (3)	C21—C22—C23—C28	178.9 (3)
C7—C2—C3—C4	−0.2 (4)	C22—C17—C18—C19	−0.2 (4)
C7—C8—C9—C10	−177.3 (3)	C22—C23—C24—C25	178.0 (3)
C7—C8—C13—C1	−2.1 (3)	C22—C23—C28—C16	1.7 (3)
C7—C8—C13—C12	178.8 (2)	C22—C23—C28—C27	−178.7 (2)
C8—C9—C10—C11	−0.9 (4)	C23—C24—C25—C26	1.1 (4)
C9—C8—C13—C1	179.7 (2)	C24—C23—C28—C16	−179.0 (2)
C9—C8—C13—C12	0.5 (4)	C24—C23—C28—C27	0.6 (4)
C9—C10—C11—C12	0.3 (4)	C24—C25—C26—C27	−0.4 (4)
C10—C11—C12—C13	0.8 (4)	C25—C26—C27—C28	−0.2 (4)
C11—C12—C13—C1	179.9 (3)	C26—C27—C28—C16	179.6 (3)
C11—C12—C13—C8	−1.2 (4)	C26—C27—C28—C23	0.1 (4)
C13—C1—C2—C3	178.0 (2)	C28—C16—C17—C18	−178.6 (3)
C13—C1—C2—C7	−2.6 (3)	C28—C16—C17—C22	2.1 (3)
C13—C1—C14—O2	−74.2 (3)	C28—C16—C29—O4	76.7 (3)
C13—C8—C9—C10	0.5 (4)	C28—C23—C24—C25	−1.2 (4)
C14—O2—C15—O1	−2.3 (4)	C29—O4—C30—O3	6.6 (4)
C14—O2—C15—N1	176.8 (2)	C29—O4—C30—N2	−173.0 (2)
C14—C1—C2—C3	−61.8 (3)	C29—C16—C17—C18	61.2 (3)
C14—C1—C2—C7	117.6 (2)	C29—C16—C17—C22	−118.1 (2)
C14—C1—C13—C8	−115.7 (2)	C29—C16—C28—C23	115.9 (2)
C14—C1—C13—C12	63.3 (4)	C29—C16—C28—C27	−63.7 (4)
C15—O2—C14—C1	150.3 (2)	C30—O4—C29—C16	−158.2 (2)

Hydrogen-bond geometry (Å, º)

D—H···*A*	*D*—H	H···*A*	*D*···*A*	*D*—H···*A*
N1—H1*B*···O3	0.91 (3)	2.06 (3)	2.955 (3)	169 (3)
N1—H1*A*···O1^{i}	0.86 (3)	2.08 (3)	2.849 (3)	149 (3)
N2—H2*A*···O1	0.85 (3)	2.13 (3)	2.967 (3)	169 (3)
N2—H2*B*···O3^{ii}	0.87 (4)	2.03 (4)	2.827 (3)	152 (3)

Symmetry codes: (i) *x*, *y*−1, *z*; (ii) *x*, *y*+1, *z*.