

6-(4-Bromophenyl)-6,7-dihydro-1,3-dioxolo[4,5-g]quinolin-8(5H)-one: bilayers built from N—H···O, C—H···O and C—H··· π (arene) hydrogen bonds

John N. Low,^a Justo Cobo,^b Paola Cuervo,^c Rodrigo Abonia^c and Christopher Glidewell^{d*}

^aDepartment of Chemistry, University of Aberdeen, Meston Walk, Old Aberdeen AB24 3UE, Scotland, ^bDepartamento de Química Inorgánica y Orgánica, Universidad de Jaén, 23071 Jaén, Spain, ^cGrupo de Investigación de Compuestos Heterocíclicos, Departamento de Química, Universidad de Valle, AA 25360, Colombia, and ^dSchool of Chemistry, University of St Andrews, Fife KY16 9ST, Scotland

Correspondence e-mail: cg@st-andrews.ac.uk

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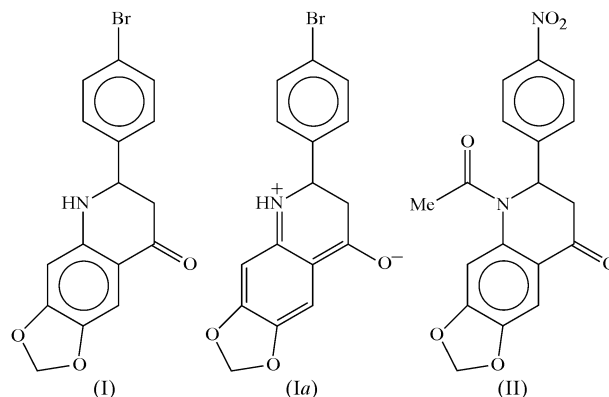
Molecules of the title compound, C₁₆H₁₂BrNO₃, exhibit a polarized molecular–electronic structure. A combination of one N—H···O hydrogen bond and one C—H···O hydrogen bond links the molecules into sheets, and pairs of sheets are linked into bilayers by a single C—H··· π (arene) hydrogen bond.

Comment

As part of a synthetic programme targeted on compounds displaying important biological properties, we have recently focused on hydroquinoline derivatives because the dioxolotetrahydroquinolin-8-one structure, for example, has been found in compounds used as antimetabolic and antitumour agents (Prager & Thredgold, 1968; Donnelly & Farrell, 1990; Kurasawa *et al.*, 2000; Zhang *et al.*, 2000). We report here the molecular and supramolecular structure of 6-(4-bromophenyl)-6,7-dihydro-1,3-dioxolo[4,5-g]quinolin-8(5H)-one, (I), which has been synthesized by 6-*endo* intramolecular cyclization from the corresponding 2-aminochalcone; the structures of a range of these precursors have been reported recently (Low, Cobo, Nogueras *et al.*, 2004).

The molecule of (I) contains a stereogenic centre at atom C10 (Fig. 1); the reference molecule was selected as one having an *S* configuration, but the centrosymmetric space group accommodates equal numbers of *R* and *S* enantiomers. In addition to the two planar carbocyclic rings, the molecule contains two heterocyclic rings, both of which are non-planar. The five-membered ring is folded across the O···O line, and for the atom sequence O1—C2—O3—C3a—C7a, the ring-puckering parameter φ_2 (Cremer & Pople, 1975) has a value of 37 (2)°, consistent with an envelope conformation (Evans &

Boeyens, 1989). For the nitrogen-containing ring, the parameters corresponding to the atom sequence N5—C5—C6—C8—C9—C10 are $\theta = 52.3$ (5)° and $\varphi = 291.5$ (6)°, corresponding closely to an envelope conformation, where the idealized values are $\theta = 54.7^\circ$ and $\varphi = (60n)^\circ$; in (I), the ring is folded along the N5···C9 line.



The bond distances in (I) (Table 1) provide evidence for some polarization of the molecular–electronic structure. Within the central ring of the fused tricyclic unit, the C3a—C4 and C7—C7a bonds are shorter than the typical values found in delocalized aromatic rings (Allen *et al.*, 1987) and are much shorter than the remaining bonds, which themselves are longer than normal for delocalized aromatic rings. In addition, the C5—N5 bond is shorter than the typical value for bonds of this type involving pyramidal N (mean value = 1.419 Å and lower quartile value = 1.412 Å), and the C6—C8 bond is again much shorter than normal for C_{ar}—COR-type bonds (mean value = 1.488 Å and lower quartile value = 1.478 Å). Finally, we note that the C8—O8 bond is also long for its type. These observations, taken together, provide evidence for the importance of the polarized form (Ia) in addition to the conventional aromatic form (I).

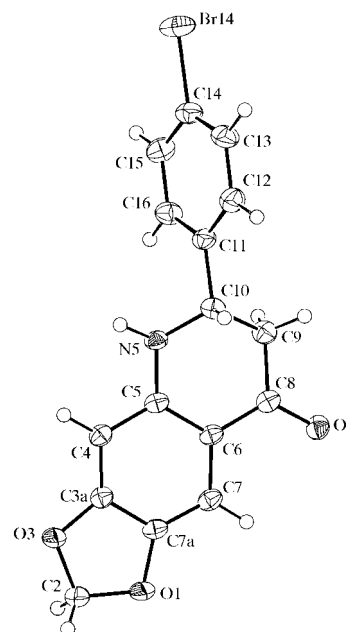


Figure 1

The *S* enantiomer of (I), showing the atom-labelling scheme. Displacement ellipsoids are drawn at the 30% probability level.

The molecules of (I) are linked by a combination of N—H···O, C—H···O and C—H··· π (arene) hydrogen bonds (Table 2) into a double-layer structure, whose formation is readily analysed in terms of the simple motifs generated by each of the individual hydrogen bonds. In the first such motif, atom N5 in the molecule at (x, y, z) acts as a hydrogen-bond donor to carbonyl atom O8 in the molecule at $(x, \frac{3}{2} - y, \frac{1}{2} + z)$, so forming a $C(6)$ chain (Bernstein *et al.*, 1995) running

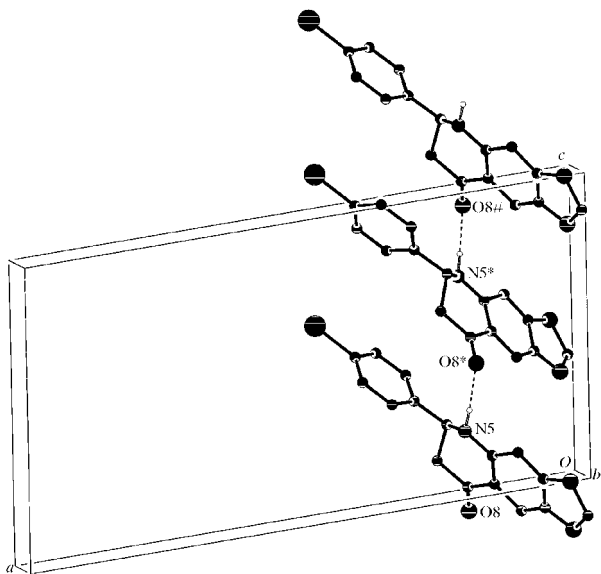


Figure 2 Part of the crystal structure of (I), showing the formation of a $C(6)$ chain along $[001]$ built from N—H···O hydrogen bonds. For clarity, H atoms not involved in the motif shown have been omitted. Atoms marked with an asterisk (*) or a hash (#) are at the symmetry positions $(x, \frac{3}{2} - y, \frac{1}{2} + z)$ and $(x, y, 1 + z)$, respectively.

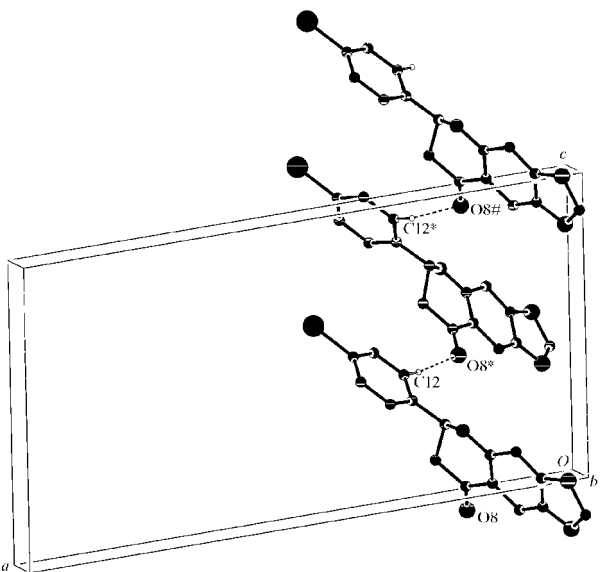


Figure 3 Part of the crystal structure of (I), showing the formation of a $C(7)$ chain along $[001]$ built from C—H···O hydrogen bonds. For clarity, H atoms not involved in the motif shown have been omitted. Atoms marked with an asterisk (*) or a hash (#) are at the symmetry positions $(x, \frac{1}{2} - y, \frac{1}{2} + z)$ and $(x, y, 1 + z)$, respectively.

parallel to the $[001]$ direction and generated by the c -glide plane at $y = \frac{3}{4}$ (Fig. 2). In addition, aryl atom C12 in the molecule at (x, y, z) acts as a hydrogen-bond donor also to atom O8 but in the molecule at $(x, \frac{1}{2} - y, \frac{1}{2} + z)$, so forming a $C(7)$ chain parallel to $[001]$, this time generated by the c -glide plane at $y = \frac{1}{4}$ (Fig. 3). The combination of these two chain motifs generates a (100) sheet in the form of a $(4,4)$ -net (Batten & Robson, 1998) built from a single type of $R_4^3(20)$ ring (Fig. 4).

Two sheets of this type, related to one another by inversion, pass through each unit cell, one each in the domains $0.03 < x < 0.41$ and $0.59 < x < 0.97$; adjacent sheets are linked into pairs by means of a C—H··· π (arene) hydrogen bond. Atom C2 in the molecule at (x, y, z) , which lies in the domain $0.03 < x < 0.41$, acts as a hydrogen-bond donor *via* atom H2A to the C3A—C7A carbocyclic ring in the molecule at $(-x, 2 - y, -z)$, which lies in the domain $-0.41 < x < -0.03$; the resulting centrosymmetric motif (Fig. 5) serves to link two adjacent sheets into a bilayer, but there are no direction-specific interactions between adjacent bilayers.

It is of interest to compare the supramolecular aggregation of (I) with that in the related compound (II) (Low, Cobo, Ortíz *et al.*, 2004), in which N—H bonds are absent. In (II), the molecules are linked into chains of rings by a combination of

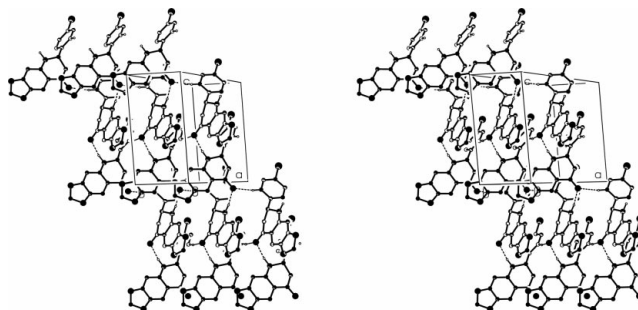


Figure 4 A stereoview of part of the crystal structure of (I), showing the formation of a (100) sheet of $R_4^3(20)$ rings. For clarity, H atoms not involved in the motifs shown have been omitted.

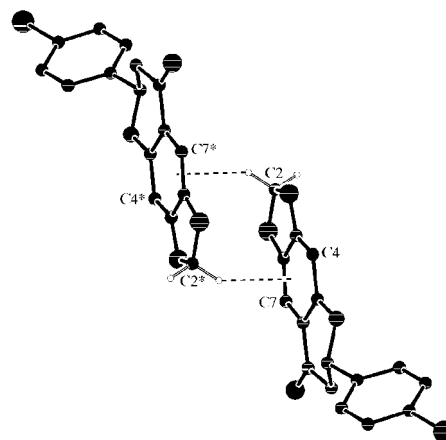


Figure 5 Part of the crystal structure of (I), showing the formation of a centrosymmetric dimer built from C—H··· π (arene) hydrogen bonds. For clarity, H atoms bonded to N atoms or to the C atoms not involved in the motif shown have been omitted. Atoms marked with an asterisk (*) are at the symmetry position $(-x, 2 - y, -z)$.

C—H...O and C—H... π (arene) hydrogen bonds, both of which utilize aromatic C—H bonds.

Experimental

For the synthesis of (I), a mixture of 1-(6-amino-1,3-benzodioxol-5-yl)-3-(4-bromophenyl)prop-2-en-1-one (0.2 g, 0.58 mmol), 2-propanol (15 ml) and 4-toluenesulfonic acid (50 mg) was heated under reflux for 2 h. After cooling, the solvent was removed under reduced pressure and the residue was purified by column chromatography on silica gel using hexane–ethyl acetate (4:1 v/v) as eluant. The product, (I) (75% yield; m.p. 490 K), is a yellow luminescent solid. MS (70 eV): *m/e* (%): 345/347 (90/85, [*M*⁺]), 190 (100, [*M*—C₆H₄Br]), 163 (61, [*M*—CH₂ = CHC₆H₄Br]). Crystals suitable for single-crystal X-ray diffraction were grown from a solution in 2-propanol.

Crystal data

C ₁₆ H ₁₂ BrNO ₃	<i>D</i> _x = 1.644 Mg m ⁻³
<i>M</i> _r = 346.18	Mo <i>K</i> α radiation
Monoclinic, <i>P</i> ₂ ₁ / <i>c</i>	Cell parameters from 3166 reflections
<i>a</i> = 21.2470 (11) Å	θ = 3.6–27.5°
<i>b</i> = 5.8263 (3) Å	μ = 2.95 mm ⁻¹
<i>c</i> = 11.4131 (6) Å	<i>T</i> = 120 (2) K
β = 98.197 (3)°	Plate, yellow
<i>V</i> = 1398.41 (13) Å ³	0.18 × 0.18 × 0.04 mm
<i>Z</i> = 4	

Data collection

Nonius KappaCCD diffractometer	2329 reflections with <i>I</i> > 2 σ (<i>I</i>)
φ scans, and ω scans with κ offsets	<i>R</i> _{int} = 0.054
Absorption correction: multi-scan	θ_{\max} = 27.5°
(<i>SADABS</i> ; Sheldrick, 2003)	<i>h</i> = -27 → 27
<i>T</i> _{min} = 0.619, <i>T</i> _{max} = 0.891	<i>k</i> = -6 → 7
14 573 measured reflections	<i>l</i> = -14 → 14
3166 independent reflections	

Refinement

Refinement on <i>F</i> ²	$w = 1/[\sigma^2(F_o^2) + (0.0578P)^2 + 2.4187P]$
$R[F^2 > 2\sigma(F^2)] = 0.046$	where $P = (F_o^2 + 2F_c^2)/3$
$wR(F^2) = 0.131$	($\Delta\sigma$) _{max} = 0.001
<i>S</i> = 1.07	$\Delta\rho_{\max} = 1.29 \text{ e \AA}^{-3}$
3166 reflections	$\Delta\rho_{\min} = -0.88 \text{ e \AA}^{-3}$
190 parameters	
H-atom parameters constrained	

Table 1

Selected interatomic distances (Å).

C3A—C4	1.365 (5)	C7a—C3a	1.396 (5)
C4—C5	1.420 (5)	C5—N5	1.368 (4)
C5—C6	1.414 (5)	C6—C8	1.447 (5)
C6—C7	1.424 (5)	C8—O8	1.241 (4)
C7—C7a	1.356 (5)		

Table 2

Hydrogen-bonding geometry (Å, °).

Cg1 is the centroid of the C3a/C4—C7/C7a ring.

<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>
N5—H5...O8 ⁱ	0.96	1.92	2.867 (3)	170
C12—H12...O8 ⁱⁱ	0.95	2.38	3.319 (5)	170
C2—H2A...Cg1 ⁱⁱⁱ	0.99	2.74	3.550 (4)	140

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

Space group *P*₂₁/*c* was uniquely assigned from the systematic absences. All H atoms were located from difference maps and then treated as riding atoms, with C—H distances of 0.95 (aromatic), 0.99 (CH₂) or 1.00 Å (aliphatic CH), and an N—H distance of 0.96 Å [*U*_{iso}(H) = 1.2*U*_{eq}(C,N)]. The atom labelling follows that used for the 1-(6-amino-1,3-benzodioxol-5-yl)-3-arylprop-2-en-1-one precursor compounds (Low, Cobo, Noguera *et al.*, 2004).

Data collection: *COLLECT* (Hooft, 1999); cell refinement: *DENZO* (Otwinowski & Minor, 1997) and *COLLECT*; data reduction: *DENZO* and *COLLECT*; program(s) used to solve structure: *OSCAIL* (McArdle, 2003) and *SHELXS97* (Sheldrick, 1997); program(s) used to refine structure: *OSCAIL* and *SHELXL97* (Sheldrick, 1997); molecular graphics: *PLATON* (Spek, 2003); software used to prepare material for publication: *SHELXL97* and *PRPKAPPA* (Ferguson, 1999).

X-Ray data were collected at the EPSRC X-ray Crystallographic Service, University of Southampton, England; the authors thank the staff for all their help and advice. JNL thanks NCR Self-Service, Dundee, for grants that have provided computing facilities for this work. RA thanks the Fundación para la Promoción de la Investigación y la Tecnología (Banco de la República) and the Universidad del Valle for financial support. PC thanks COLCIENCIAS for a doctoral fellowship. JC thanks the Junta de Andalucía and the Universidad de Jaén for financial support.

Supplementary data for this paper are available from the IUCr electronic archives (Reference: SK1778). Services for accessing these data are described at the back of the journal.

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supporting information

Acta Cryst. (2004). C60, o827–o829 [doi:10.1107/S0108270104024564]

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Computing details

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Crystal data

C₁₆H₁₂BrNO₃

$M_r = 346.18$

Monoclinic, $P2_1/c$

Hall symbol: -P 2ybc

$a = 21.2470$ (11) Å

$b = 5.8263$ (3) Å

$c = 11.4131$ (6) Å

$\beta = 98.197$ (3)°

$V = 1398.41$ (13) Å³

$Z = 4$

$F(000) = 696$

$D_x = 1.644$ Mg m⁻³

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

Cell parameters from 3166 reflections

$\theta = 3.6$ – 27.5 °

$\mu = 2.95$ mm⁻¹

$T = 120$ K

Plate, yellow

$0.18 \times 0.18 \times 0.04$ mm

Data collection

Nonius KappaCCD

diffractometer

Radiation source: fine-focus sealed X-ray tube

Graphite monochromator

φ scans, and ω scans with κ offsets

Absorption correction: multi-scan

(*SADABS*; Sheldrick, 2003)

$T_{\min} = 0.619$, $T_{\max} = 0.891$

14573 measured reflections

3166 independent reflections

2329 reflections with $I > 2\sigma(I)$

$R_{\text{int}} = 0.054$

$\theta_{\max} = 27.5$ °, $\theta_{\min} = 3.6$ °

$h = -27 \rightarrow 27$

$k = -6 \rightarrow 7$

$l = -14 \rightarrow 14$

Refinement

Refinement on F^2

Least-squares matrix: full

$R[F^2 > 2\sigma(F^2)] = 0.046$

$wR(F^2) = 0.131$

$S = 1.07$

3166 reflections

190 parameters

0 restraints

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

$$w = 1/[\sigma^2(F_o^2) + (0.0578P)^2 + 2.4187P]$$

where $P = (F_o^2 + 2F_c^2)/3$
 $(\Delta/\sigma)_{\max} = 0.001$

$$\Delta\rho_{\max} = 1.29 \text{ e } \text{\AA}^{-3}$$

$$\Delta\rho_{\min} = -0.88 \text{ e } \text{\AA}^{-3}$$

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

	x	y	z	$U_{\text{iso}}^*/U_{\text{eq}}$
Br14	0.475584 (18)	0.66273 (8)	0.63741 (3)	0.04391 (18)
O1	0.03463 (12)	1.0776 (5)	-0.1556 (2)	0.0330 (6)
O3	0.04465 (12)	1.3103 (4)	0.0106 (2)	0.0294 (6)
O8	0.20169 (12)	0.4244 (4)	-0.0591 (2)	0.0281 (5)
N5	0.21863 (13)	0.8716 (5)	0.2189 (2)	0.0245 (6)
C2	0.01441 (18)	1.2891 (6)	-0.1107 (3)	0.0291 (8)
C3A	0.08805 (16)	1.1376 (6)	0.0287 (3)	0.0228 (7)
C4	0.13109 (16)	1.0989 (6)	0.1274 (3)	0.0237 (7)
C5	0.17195 (15)	0.9066 (6)	0.1249 (3)	0.0223 (7)
C6	0.16483 (15)	0.7576 (6)	0.0261 (3)	0.0225 (7)
C7	0.11890 (16)	0.8058 (6)	-0.0744 (3)	0.0255 (7)
C7A	0.08238 (16)	0.9957 (6)	-0.0708 (3)	0.0250 (7)
C8	0.20693 (16)	0.5629 (6)	0.0243 (3)	0.0232 (7)
C9	0.25972 (17)	0.5399 (6)	0.1262 (3)	0.0275 (7)
C10	0.24398 (17)	0.6416 (6)	0.2419 (3)	0.0268 (7)
C11	0.30174 (16)	0.6497 (6)	0.3375 (3)	0.0258 (7)
C12	0.31097 (18)	0.4750 (7)	0.4206 (3)	0.0331 (8)
C13	0.36354 (18)	0.4776 (7)	0.5091 (3)	0.0343 (8)
C14	0.40543 (17)	0.6562 (7)	0.5139 (3)	0.0294 (8)
C15	0.39783 (18)	0.8316 (7)	0.4331 (3)	0.0332 (8)
C16	0.34613 (18)	0.8277 (6)	0.3441 (3)	0.0311 (8)
H2A	-0.0324	1.2904	-0.1142	0.035*
H2B	0.0268	1.4190	-0.1584	0.035*
H4	0.1336	1.1962	0.1947	0.028*
H5	0.2121	0.9569	0.2881	0.029*
H7	0.1140	0.7081	-0.1418	0.031*
H9A	0.2981	0.6171	0.1052	0.033*
H9B	0.2700	0.3752	0.1386	0.033*
H10	0.2106	0.5444	0.2708	0.032*
H12	0.2813	0.3525	0.4173	0.040*
H13	0.3701	0.3566	0.5653	0.041*
H15	0.4276	0.9541	0.4380	0.040*
H16	0.3408	0.9474	0.2870	0.037*

Atomic displacement parameters (\AA^2)

	U^{11}	U^{22}	U^{33}	U^{12}	U^{13}	U^{23}
Br14	0.0303 (2)	0.0694 (3)	0.0291 (2)	-0.0001 (2)	-0.00602 (16)	0.00020 (18)
O1	0.0359 (14)	0.0393 (15)	0.0202 (12)	0.0087 (12)	-0.0083 (10)	-0.0031 (10)
O3	0.0334 (14)	0.0325 (14)	0.0200 (12)	0.0081 (11)	-0.0039 (10)	-0.0005 (9)
O8	0.0378 (14)	0.0283 (13)	0.0188 (12)	0.0023 (11)	0.0063 (10)	0.0000 (9)

N5	0.0249 (15)	0.0318 (16)	0.0159 (13)	0.0030 (12)	-0.0003 (11)	-0.0014 (11)
C2	0.0303 (19)	0.030 (2)	0.0251 (17)	0.0019 (15)	-0.0030 (14)	0.0011 (14)
C3A	0.0236 (16)	0.0267 (17)	0.0188 (16)	-0.0007 (14)	0.0049 (13)	-0.0003 (13)
C4	0.0269 (17)	0.0268 (17)	0.0177 (16)	-0.0021 (14)	0.0041 (13)	0.0003 (12)
C5	0.0205 (16)	0.0291 (18)	0.0174 (16)	-0.0037 (13)	0.0036 (12)	0.0014 (12)
C6	0.0207 (16)	0.0289 (17)	0.0180 (15)	-0.0028 (14)	0.0031 (13)	-0.0003 (13)
C7	0.0243 (17)	0.0322 (19)	0.0201 (16)	-0.0027 (14)	0.0040 (13)	-0.0034 (13)
C7A	0.0242 (16)	0.0317 (19)	0.0185 (16)	-0.0017 (14)	0.0006 (13)	0.0012 (13)
C8	0.0239 (17)	0.0287 (18)	0.0180 (16)	-0.0039 (14)	0.0065 (13)	0.0013 (13)
C9	0.0296 (18)	0.032 (2)	0.0215 (17)	0.0022 (15)	0.0060 (14)	0.0020 (14)
C10	0.0250 (17)	0.0304 (19)	0.0244 (17)	0.0014 (15)	0.0013 (14)	0.0030 (14)
C11	0.0233 (17)	0.0334 (19)	0.0205 (16)	0.0032 (15)	0.0026 (13)	-0.0038 (13)
C12	0.034 (2)	0.0290 (19)	0.035 (2)	-0.0031 (16)	-0.0010 (16)	-0.0001 (15)
C13	0.037 (2)	0.034 (2)	0.0298 (19)	0.0034 (17)	-0.0038 (15)	0.0076 (15)
C14	0.0220 (17)	0.042 (2)	0.0241 (18)	0.0026 (16)	0.0019 (14)	-0.0015 (15)
C15	0.0260 (18)	0.038 (2)	0.035 (2)	-0.0101 (16)	0.0033 (15)	0.0000 (16)
C16	0.0319 (19)	0.033 (2)	0.0271 (18)	-0.0002 (16)	0.0008 (15)	0.0069 (15)

Geometric parameters (Å, °)

O1—C7A	1.383 (4)	C7—H7	0.95
O1—C2	1.424 (5)	C8—C9	1.502 (5)
C2—O3	1.446 (4)	C9—C10	1.528 (5)
C2—H2A	0.99	C9—H9A	0.99
C2—H2B	0.99	C9—H9B	0.99
O3—C3A	1.360 (4)	C10—C11	1.522 (5)
C3A—C4	1.365 (5)	C10—H10	1.00
C4—C5	1.420 (5)	C11—C12	1.386 (5)
C5—C6	1.414 (5)	C11—C16	1.397 (5)
C6—C7	1.424 (5)	C12—C13	1.395 (5)
C7—C7A	1.356 (5)	C12—H12	0.95
C7A—C3A	1.396 (5)	C13—C14	1.366 (5)
C5—N5	1.368 (4)	C13—H13	0.95
C6—C8	1.447 (5)	C14—C15	1.370 (5)
C8—O8	1.241 (4)	C14—Br14	1.901 (3)
C4—H4	0.95	C15—C16	1.386 (5)
N5—C10	1.454 (4)	C15—H15	0.95
N5—H5	0.96	C16—H16	0.95
C7A—O1—C2	106.0 (3)	C6—C8—C9	117.0 (3)
O1—C2—O3	107.6 (3)	C8—C9—C10	113.8 (3)
O1—C2—H2A	110.2	C8—C9—H9A	108.8
O3—C2—H2A	110.2	C10—C9—H9A	108.8
O1—C2—H2B	110.2	C8—C9—H9B	108.8
O3—C2—H2B	110.2	C10—C9—H9B	108.8
H2A—C2—H2B	108.5	H9A—C9—H9B	107.7
C3A—O3—C2	106.3 (2)	N5—C10—C11	109.9 (3)
O3—C3A—C4	127.4 (3)	N5—C10—C9	108.8 (3)

O3—C3A—C7A	109.7 (3)	C11—C10—C9	112.2 (3)
C4—C3A—C7A	122.9 (3)	N5—C10—H10	108.6
C3A—C4—C5	117.0 (3)	C11—C10—H10	108.6
C3A—C4—H4	121.5	C9—C10—H10	108.6
C5—C4—H4	121.5	C12—C11—C16	118.7 (3)
N5—C5—C6	121.1 (3)	C12—C11—C10	119.3 (3)
N5—C5—C4	118.6 (3)	C16—C11—C10	122.1 (3)
C6—C5—C4	120.3 (3)	C11—C12—C13	120.5 (3)
C5—N5—C10	119.2 (3)	C11—C12—H12	119.7
C5—N5—H5	113.2	C13—C12—H12	119.7
C10—N5—H5	114.9	C14—C13—C12	119.2 (3)
C5—C6—C7	120.3 (3)	C14—C13—H13	120.4
C5—C6—C8	119.8 (3)	C12—C13—H13	120.4
C7—C6—C8	119.8 (3)	C13—C14—C15	121.9 (3)
C7A—C7—C6	117.8 (3)	C13—C14—Br14	118.9 (3)
C7A—C7—H7	121.1	C15—C14—Br14	119.3 (3)
C6—C7—H7	121.1	C14—C15—C16	119.1 (3)
C7—C7A—O1	128.8 (3)	C14—C15—H15	120.5
C7—C7A—C3A	121.7 (3)	C16—C15—H15	120.5
O1—C7A—C3A	109.5 (3)	C15—C16—C11	120.7 (3)
O8—C8—C6	122.2 (3)	C15—C16—H16	119.7
O8—C8—C9	120.8 (3)	C11—C16—H16	119.7
C7A—O1—C2—O3	-8.9 (4)	C5—C6—C8—O8	178.4 (3)
O1—C2—O3—C3A	9.1 (4)	C7—C6—C8—O8	-5.3 (5)
C2—O3—C3A—C4	174.9 (3)	C5—C6—C8—C9	-4.3 (5)
C2—O3—C3A—C7A	-5.8 (4)	C7—C6—C8—C9	172.1 (3)
O3—C3A—C4—C5	-179.7 (3)	O8—C8—C9—C10	-153.3 (3)
C7A—C3A—C4—C5	1.2 (5)	C6—C8—C9—C10	29.3 (4)
C3A—C4—C5—N5	175.5 (3)	C5—N5—C10—C11	171.2 (3)
C3A—C4—C5—C6	-3.4 (5)	C5—N5—C10—C9	48.0 (4)
C6—C5—N5—C10	-24.8 (5)	C8—C9—C10—N5	-49.0 (4)
C4—C5—N5—C10	156.3 (3)	C8—C9—C10—C11	-170.9 (3)
N5—C5—C6—C7	-175.6 (3)	N5—C10—C11—C12	142.0 (3)
C4—C5—C6—C7	3.3 (5)	C9—C10—C11—C12	-96.8 (4)
N5—C5—C6—C8	0.8 (5)	N5—C10—C11—C16	-38.2 (4)
C4—C5—C6—C8	179.7 (3)	C9—C10—C11—C16	83.0 (4)
C5—C6—C7—C7A	-0.8 (5)	C16—C11—C12—C13	0.1 (5)
C8—C6—C7—C7A	-177.1 (3)	C10—C11—C12—C13	179.9 (3)
C6—C7—C7A—O1	-179.3 (3)	C11—C12—C13—C14	0.9 (6)
C6—C7—C7A—C3A	-1.5 (5)	C12—C13—C14—C15	-1.0 (6)
C2—O1—C7A—C7	-176.5 (4)	C12—C13—C14—Br14	178.2 (3)
C2—O1—C7A—C3A	5.4 (4)	C13—C14—C15—C16	0.1 (6)
O3—C3A—C7A—C7	-177.9 (3)	Br14—C14—C15—C16	-179.1 (3)
C4—C3A—C7A—C7	1.4 (5)	C14—C15—C16—C11	0.9 (6)
O3—C3A—C7A—O1	0.3 (4)	C12—C11—C16—C15	-1.0 (5)
C4—C3A—C7A—O1	179.6 (3)	C10—C11—C16—C15	179.2 (3)

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>
N5—H5 \cdots O8 ⁱ	0.96	1.92	2.867 (3)	170
C12—H12 \cdots O8 ⁱⁱ	0.95	2.38	3.319 (5)	170
C2—H2 <i>A</i> \cdots Cg1 ⁱⁱⁱ	0.99	2.74	3.550 (4)	140

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