

Crystal structure of 5-benzyl-8-bromo-2-methyl-1,3-oxazolo[4,5-c][1,8]naphthyridin-4(5*H*)-one

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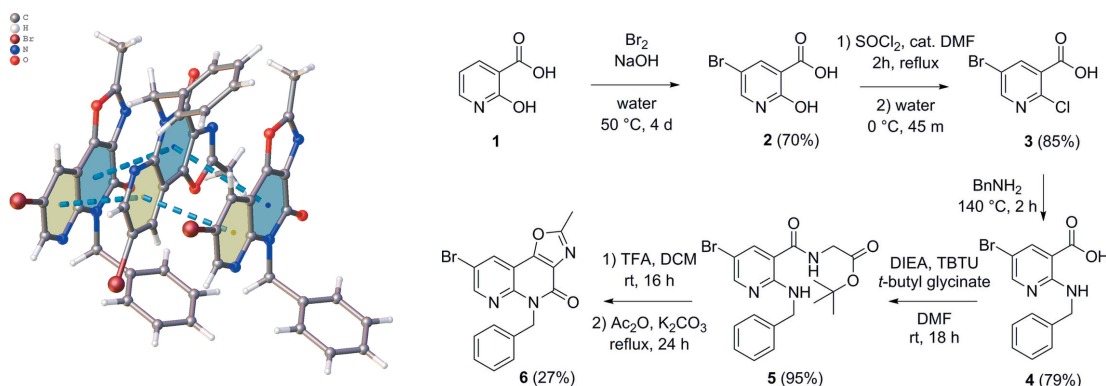
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**Keywords:** crystal structure; benzodiazepine drugs; oxazolophthyridone;  $\pi$ - $\pi$  stacking.**CCDC reference:** 1541539**Supporting information:** this article has supporting information at journals.iucr.org/e

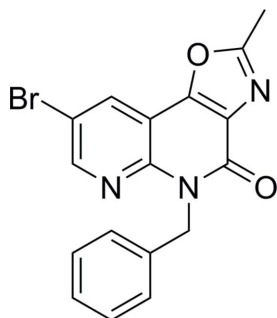
The title compound,  $C_{17}H_{12}BrN_3O_2$ , was unexpectedly isolated during an attempt to synthesize pyridodiazepinediones and identified as an oxazolophthyridinone derivative. The almost planar oxazolophthyridinone ring (r.m.s. deviation = 0.016 Å) makes a dihedral angle of 61.6 (2)° with the phenyl ring. In the crystal, columns of molecules stacked along the *a* axis are formed by  $\pi$ - $\pi$  interactions between the six-membered rings of the oxazolophthyridone moieties [centroid-to-centroid distances = 3.494 (2)–3.906 (3) Å], which further interact through C–H... $\pi$  contacts with the phenyl rings.

## 1. Chemical context

While benzodiazepine drugs have been amongst the most prescribed medication globally since their discovery in the 1950s, the search for structurally related biologically active compounds is of major relevance to the pharmaceutical industry (Washton & Zweben, 2011). Previous work in our group dealing with the construction of pyridodiazepinediones (PZDs; Van den Bogaert *et al.*, 2010) led unexpectedly to the isolation of a tricyclic compound, which was later identified as oxazolophthyridinone (ONO) **6** (Fig. 1). Commercially available 2-hydroxynicotinic acid **1** was converted to dihalonicotinic acid **3** via two sequential halogenation reactions (Van den Bogaert *et al.*, 2010; Gero *et al.*, 1989; Haché *et al.*, 2002), after which a benzylamine substituent was introduced yielding the aza-anthranilic acid derivative **4**. Next, ester compound **5** was prepared from intermediate **4** and *tert*-butyl glycinate using a standard coupling procedure. Finally, *tert*-butyl ester **5** was deprotected *in situ* and reacted with acetic anhydride, yielding tricyclic

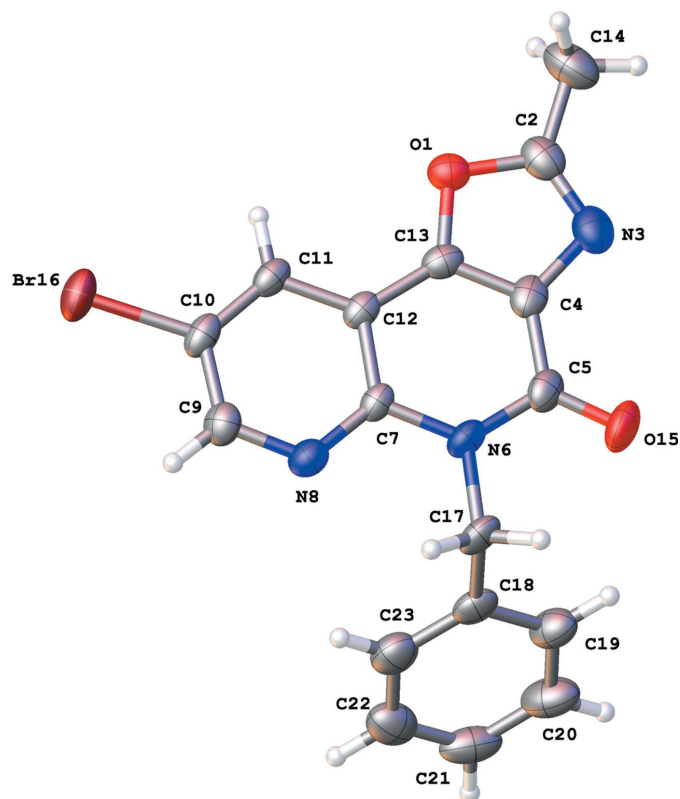
**Figure 1**Synthesis of the title compound **6** as unexpectedly formed during the synthesis of pyridodiazepinediones.

compound **6**. After exploration and optimization of the revealed cascade reaction towards the closely related oxazoloquinolinone scaffold (Vrijdag *et al.*, 2013), we decided to turn our attention to the remarkable tricyclic product **6** isolated during the initial investigation. The ONO structural motif contained in compound **6** is brought into relation with both antibacterial (Ratcliffe *et al.*, 2015) and histamine 4 receptor antagonist (Ho *et al.*, 2013) activities. Hence, new synthetic routes towards ONOs are currently being developed in our laboratory (Vrijdag *et al.*, 2017). Here we present the molecular and crystal structure of the title compound **6**.



## 2. Structural commentary

Crystals of **6** belong to the orthorhombic space group *Pna*<sub>2</sub><sup>1</sup> with one molecule in the asymmetric unit (Fig. 2). The



**Figure 2**  
View of the asymmetric unit of the title compound **6**, showing the atom-labelling scheme. Displacement ellipsoids are drawn at the 50% probability level. H atoms are shown as small circles of arbitrary radii.

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

Cg3 is the centroid of the C18–C23 ring.

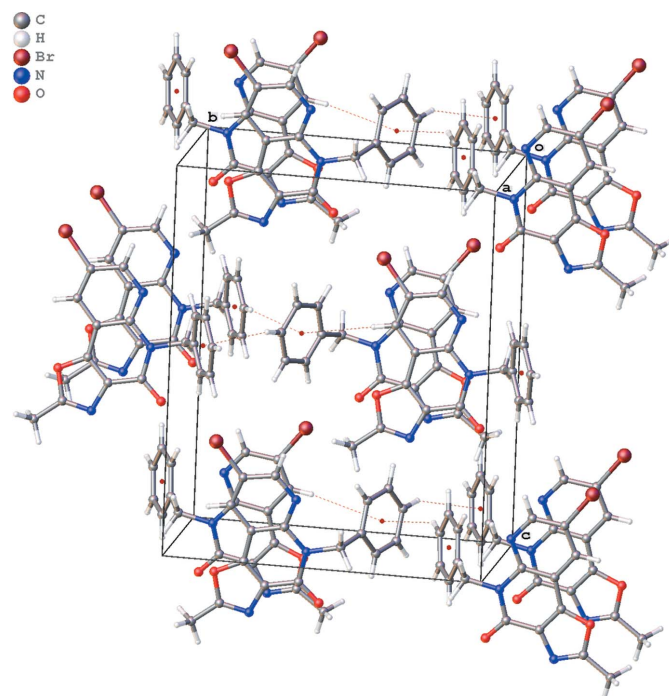
<i>D</i> –H··· <i>A</i>	<i>D</i> –H	H··· <i>A</i>	<i>D</i> ··· <i>A</i>	<i>D</i> –H··· <i>A</i>
C21–H21···Cg3 <sup>i</sup>	0.95	2.82	3.604 (6)	141
C11–H11···Cg3 <sup>ii</sup>	0.95	3.31	4.239 (6)	167

Symmetry codes: (i)  $x - \frac{1}{2}, -y + \frac{5}{2}, z$ ; (ii)  $x + \frac{1}{2}, -y + \frac{3}{2}, z$ .

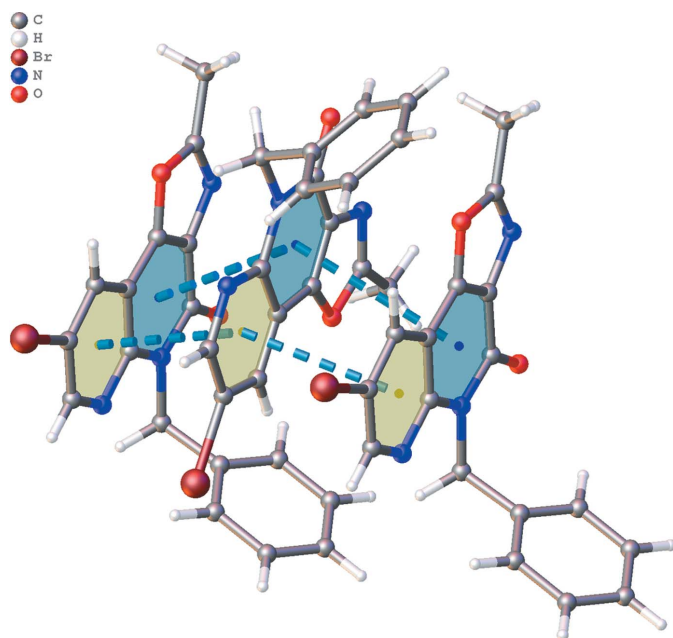
oxazolonaphthyridine ring is almost planar (r.m.s. deviation = 0.016 Å) with the substituents C14 [0.082 (6) Å], O15 [−0.023 (4) Å], Br16 [−0.012 (1) Å] and C17 [0.034 (5) Å] situated in the same plane (deviations from plane given in parenthesis). The dihedral angle between the mean planes through the oxazole and pyridine rings is 2.0 (2)°. The dihedral angle between the oxazolonaphthyridine ring system and the phenyl rings is 61.6 (2)°. Both H atoms of C17 are in close contact with the neighboring atoms N8 and O15 (H17A···N8 = 2.36 Å and H17B···O15 = 2.36 Å). No classical hydrogen bonds are observed.

## 3. Supramolecular features

The crystal packing (Fig. 3) is characterized by  $\pi$ – $\pi$  interactions between the six-membered rings of the oxazolonaphthyridone ring systems, resulting in columns of stacked molecules along the *a* axis [Fig. 4; Cg1···Cg1<sup>i</sup> = 3.494 (2) Å and Cg2···Cg2<sup>i</sup> = 3.906 (3) Å; Cg1 and Cg2 are the centroids of the rings C7/N8/C9–C12 and C4/C5/N6/C7/C12/C13, respectively; symmetry code: (i)  $x + \frac{1}{2}, -y + \frac{3}{2}, z$ ]. Molecules in



**Figure 3**  
View of the crystal packing for the title compound **6**, showing C–H··· $\pi$  interactions (red dotted lines) between the C18–C23 phenyl rings.



**Figure 4**  
Part of the crystal packing of the title compound **6**, showing  $\pi$ - $\pi$  interactions between the C7/N8/C9-C12 (blue) and C4/C5/N6/C7/C12/C13 (yellow) rings.

neighboring columns show further C—H... $\pi$  interactions between the C18-C23 phenyl rings (Fig. 3, Table 1). The closest contact of Br16 in the packing is with atom O15<sup>ii</sup> [2.874 (4) Å; symmetry code: (ii)  $-x + \frac{1}{2}, y - \frac{1}{2}, z - \frac{1}{2}$ ].

#### 4. Database survey

A search of the Cambridge Structural Database (CSD, Version 5.38, last update February 2017; Groom *et al.*, 2016) for a [1,3]oxazolo[4,5-*c*]-1,8-naphthyridin-4(5*H*)-one ring skeleton gave no hits. The closest ring skeleton is found in 2,5-dimethyl[1,3]oxazolo[4,5-*c*]quinolin-4(5*H*)-one (refcode HOJTUW; Latypov *et al.*, 2008), which contains a quinolinone ring system instead of a naphthyridinone ring system. The oxazoloquinoline ring is almost planar (r.m.s. deviation = 0.015 Å) with a dihedral angle between the oxazole and phenyl rings of 1.90 (13)°.

#### 5. Synthesis and crystallization

##### Synthesis of 5-bromo-2-hydroxynicotinic acid (**2**), 5-bromo-2-chloronicotinic acid (**3**), and 2-(benzylamino)-5-bromonicotinic acid (**4**):

Substituted nicotinic acids **2-4** were synthesized following the protocols of Van den Bogaert *et al.* (2010). Analytical data matches literature data.

##### Synthesis of *tert*-butyl *N*-{[2-(benzylamino)-5-bromopyridin-3-yl]carbonyl}glycinate (**5**):

2-(Benzylamino)-5-bromonicotinic acid **4** (50 mg, 0.16 mmol) was dissolved in dimethylformamide under an Ar atmosphere, and di-isopropylethylamine (27  $\mu$ l, 0.16 mmol)

**Table 2**  
Experimental details.

Crystal data	
Chemical formula	C <sub>17</sub> H <sub>12</sub> BrN <sub>3</sub> O <sub>2</sub>
<i>M<sub>r</sub></i>	370.21
Crystal system, space group	Orthorhombic, <i>Pna</i> 2 <sub>1</sub>
Temperature (K)	200
<i>a</i> , <i>b</i> , <i>c</i> (Å)	6.7150 (13), 13.504 (3), 16.757 (3)
<i>V</i> (Å <sup>3</sup> )	1519.5 (5)
<i>Z</i>	4
Radiation type	Mo <i>K</i> $\alpha$
$\mu$ (mm <sup>-1</sup> )	2.72
Crystal size (mm)	0.3 $\times$ 0.3 $\times$ 0.2
Data collection	
Diffractometer	Enraf-Nonius CAD-4
Absorption correction	$\psi$ scan (North <i>et al.</i> , 1968)
<i>T<sub>min</sub></i> , <i>T<sub>max</sub></i>	0.522, 0.578
No. of measured, independent and observed [ <i>I</i> > 2 $\sigma$ ( <i>I</i> )] reflections	1429, 1429, 1279
<i>R<sub>int</sub></i>	0.049
( <i>sin</i> $\theta$ / $\lambda$ ) <sub>max</sub> (Å <sup>-1</sup> )	0.601
Refinement	
<i>R</i> [ <i>F</i> <sup>2</sup> > 2 $\sigma$ ( <i>F</i> <sup>2</sup> )], <i>wR</i> ( <i>F</i> <sup>2</sup> ), <i>S</i>	0.027, 0.069, 1.16
No. of reflections	1429
No. of parameters	209
No. of restraints	1
H-atom treatment	H-atom parameters constrained
$\Delta\rho_{max}$ , $\Delta\rho_{min}$ (e Å <sup>-3</sup> )	0.34, -0.27
Absolute structure	No quotients, so Flack parameter determined by classical intensity fit
Absolute structure parameter	0.000 (12)

Computer programs: *CAD-4 EXPRESS* (Enraf-Nonius, 1989), *DREAR* (Blessing, 1987), *SHELXS* (Sheldrick, 2008), *SHELXL2014/7* (Sheldrick, 2015) and *OLEX2* (Dolomanov *et al.*, 2009).

and benzotriazolyl tetramethyluronium fluoroborate (TBTU, 57 mg, 0.18 mmol) were subsequently added to the mixture. The reaction was stirred at room temperature for 15 m, and *t*-butyl glycinate (24  $\mu$ l, 0.18 mmol) was added. The reaction was continued at room temperature for 18 h, after which the mixture was concentrated under reduced pressure. The residue was purified using silica gel chromatography (heptane/ethyl acetate, 8:2 *v/v*) to yield compound **5** (64 mg, yield 95%).

IR (Perkin-Elmer 1720 FTIR, KBr, cm<sup>-1</sup>):  $\nu$  = 1705 (*s*, CO ester), 1648 (*s*, CO amide). <sup>1</sup>H NMR [Bruker 400 Avance, 400 MHz, CDCl<sub>3</sub>,  $\delta$  (ppm), *J* (Hz)]: 8.42 (*t*, 1H, *J* = 5, CH), 8.21 (*d*, 1H, *J* = 2, CH), 7.76 (*d*, 1H, *J* = 2, CH), 7.34-7.22 (*m*, 5H, CH), 6.84 (*t*, 1H, *J* = 5, CH), 4.65 (*d*, 2H, *J* = 6, CH<sub>2</sub>), 4.02 (*d*, 2H, *J* = 5, CH<sub>2</sub>), 1.49 (*s*, 9H, CH<sub>3</sub>). <sup>13</sup>C NMR [Bruker 400 Avance, 101 MHz, CDCl<sub>3</sub>,  $\delta$  (ppm)]: 169.4, 167.1, 156.3, 152.6, 139.3, 137.6, 128.6, 127.6, 127.1, 110.6, 104.4, 82.9, 45.0, 42.3, 28.1.

##### Synthesis of 5-benzyl-8-bromo-2-methyl[1,3]oxazolo[4,5-*c*]-1,8-naphthyridin-4(5*H*)-one (**6**):

A mixture of *tert*-butyl *N*-{[2-(benzylamino)-5-bromopyridin-3-yl]carbonyl}glycinate **5** (50 mg, 0.12 mmol) and dichloromethane (2.25 mL) was cooled to 273 K, after which trifluoroacetic acid (0.75 mL) was added. The reaction was continued at room temperature for 16 h, concentrated under reduced pressure, and dried under high vacuum. The obtained crude acid was combined with K<sub>2</sub>CO<sub>3</sub> (38 mg, 0.28 mmol) and

acetic anhydride (0.5 mL) under an Ar atmosphere and the mixture was stirred at room temperature for 30 m. Subsequently the reaction was heated to reflux for 24 h, after which the mixture was concentrated under reduced pressure. The residue was purified using silica gel chromatography (dichloromethane/methanol, 99:1 *v/v*) to yield the title compound (12 mg, yield 27%). Light-brown prismatic crystals were grown by diffusion of pentane in a chloroform solution of the title compound.

IR (Perkin–Elmer 1720 FTIR, NaCl,  $\text{cm}^{-1}$ ):  $\nu = 1683$  (*s*, CO amide).  $^1\text{H}$  NMR [Bruker 400 Avance, 400 MHz,  $\text{CDCl}_3$ ,  $\delta$  (ppm), *J* (Hz)]: 8.65 (*d*, 1H, *J* = 2, CH), 8.27 (*d*, 1H, *J* = 2, CH), 7.48 (*dd*, 2H, *J* = 7, 1, CH), 7.26–7.21 (*m*, 3H, CH), 5.80 (*s*, 2H,  $\text{CH}_2$ ), 2.71 (*s*, 3H,  $\text{CH}_3$ ).  $^{13}\text{C}$  NMR [Bruker 400 Avance, 101 MHz,  $\text{CDCl}_3$ ,  $\delta$  (ppm)]: 164.6, 157.3, 150.2, 149.9, 146.6, 137.5, 131.5, 131.0, 128.9, 128.4, 127.5, 113.9, 108.5, 44.8, 14.5.

## 6. Refinement

Crystal data, data collection and structure refinement details are summarized in Table 2. All H atoms were placed in calculated positions with C–H = 0.95 Å for aromatic, C–H = 0.98 Å for  $\text{CH}_3$  or C–H = 0.99 Å for  $\text{CH}_2$  H atoms, and included in the refinement in a riding model with  $U_{\text{iso}}(\text{H}) = 1.2$  or  $1.5U_{\text{eq}}(\text{C})$ .

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## References

- Blessing, R. H. (1987). *Crystallogr. Rev.* **1**, 3–58.
- Dolomanov, O. V., Bourhis, L. J., Gildea, R. J., Howard, J. A. K. & Puschmann, H. (2009). *J. Appl. Cryst.* **42**, 339–341.
- Enraf–Nonius (1989). *CAD-4 EXPRESS*. Enraf–Nonius, Delft, The Netherlands.
- Gero, T. W., Jaques, L. W., Mays, R. P., Reid, D. H., Shamblee, D. A. & Lo, Y. S. (1989). *Synth. Commun.* **19**, 553–559.
- Groom, C. R., Bruno, I. J., Lightfoot, M. P. & Ward, S. C. (2016). *Acta Cryst.* **B72**, 171–179.
- Haché, B., Duceppe, J. S. & Beaulieu, P. L. (2002). *Synthesis*, pp. 528–532.
- Ho, P. S., Yoon, D. O., Han, S. Y., Lee, W. I., Kim, J. S., Park, W. S., Ahn, S. O. & Kim, H. J. (2013). WO Patent 048214.
- Latypov, S., Balandina, A., Boccalini, M., Matteucci, A., Usachev, K. & Chimichi, S. (2008). *Eur. J. Org. Chem.* pp. 4640–4646.
- North, A. C. T., Phillips, D. C. & Mathews, F. S. (1968). *Acta Cryst.* **A24**, 351–359.
- Ratcliffe, A., Huxley, A., Lyth, D., Noonan, G., Kirk, R., Uosis-Martin, M. & Stokes, N. (2015). WO Patent 155549.
- Sheldrick, G. M. (2008). *Acta Cryst.* **A64**, 112–122.
- Sheldrick, G. M. (2015). *Acta Cryst.* **C71**, 3–8.
- Van den Bogaert, A. M., Nelissen, J., Ovaere, M., Van Meervelt, L., Compennolle, F. & De Borggraeve, W. M. (2010). *Eur. J. Org. Chem.* pp. 5397–5401.
- Vrijdag, J. L., De Ruyscher, D. & De Borggraeve, W. M. (2017). *Eur. J. Org. Chem.* pp. 1465–1474.
- Vrijdag, J. L., Van den Bogaert, A. M. & De Borggraeve, W. M. (2013). *Org. Lett.* **15**, 1052–1055.
- Washton, A. M. & Zweben, J. E. (2011). *Treating Alcohol and Drug Problems in Psychotherapy Practice*, p. 47. New York: Guilford Press.

## supporting information

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## Crystal structure of 5-benzyl-8-bromo-2-methyl-1,3-oxazolo[4,5-c][1,8]naphthyridin-4(5H)-one

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### Computing details

Data collection: *CAD-4 EXPRESS* (Enraf–Nonius, 1989); cell refinement: *CAD-4 EXPRESS* (Enraf–Nonius, 1989); data reduction: *DREAR* (Blessing, 1987); program(s) used to solve structure: *SHELXS* (Sheldrick, 2008); program(s) used to refine structure: *SHELXL2014/7* (Sheldrick, 2015); molecular graphics: *OLEX2* (Dolomanov *et al.*, 2009); software used to prepare material for publication: *OLEX2* (Dolomanov *et al.*, 2009).

### 5-Benzyl-8-bromo-2-methyl[1,3]oxazolo[4,5-c]-1,8-naphthyridin-4(5H)-one

#### Crystal data

$C_{17}H_{12}BrN_3O_2$

$M_r = 370.21$

Orthorhombic, *Pna*2<sub>1</sub>

$a = 6.7150$  (13) Å

$b = 13.504$  (3) Å

$c = 16.757$  (3) Å

$V = 1519.5$  (5) Å<sup>3</sup>

$Z = 4$

$F(000) = 744$

$D_x = 1.618$  Mg m<sup>-3</sup>

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

Cell parameters from 25 reflections

$\theta = 1.9$ – $25.3^\circ$

$\mu = 2.72$  mm<sup>-1</sup>

$T = 200$  K

Prism, light brown

$0.3 \times 0.3 \times 0.2$  mm

#### Data collection

Enraf–Nonius CAD-4  
diffractometer

Radiation source: fine-focus sealed tube

Graphite monochromator

$\omega/2\theta$  scans

Absorption correction:  $\psi$  scan  
(North *et al.*, 1968)

$T_{\min} = 0.522$ ,  $T_{\max} = 0.578$

1429 measured reflections

1429 independent reflections

1279 reflections with  $I > 2\sigma(I)$

$R_{\text{int}} = 0.049$

$\theta_{\max} = 25.3^\circ$ ,  $\theta_{\min} = 1.9^\circ$

$h = 0 \rightarrow 8$

$k = 0 \rightarrow 16$

$l = 0 \rightarrow 20$

3 standard reflections every 97 reflections

intensity decay: 0.5%

#### Refinement

Refinement on  $F^2$

Least-squares matrix: full

$R[F^2 > 2\sigma(F^2)] = 0.027$

$wR(F^2) = 0.069$

$S = 1.16$

1429 reflections

209 parameters

1 restraint

Primary atom site location: structure-invariant  
direct methods

Hydrogen site location: inferred from  
neighbouring sites

H-atom parameters constrained

$w = 1/[\sigma^2(F_o^2) + (0.0221P)^2 + 0.5935P]$

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

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

$\Delta\rho_{\max} = 0.34$  e Å<sup>-3</sup>

$$\Delta\rho_{\min} = -0.27 \text{ e } \text{\AA}^{-3}$$

Absolute structure: No quotients, so Flack  
parameter determined by classical intensity fit  
Absolute structure parameter: 0.000 (12)

### 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 ( $\text{\AA}^2$ )

	<i>x</i>	<i>y</i>	<i>z</i>	$U_{\text{iso}}^*/U_{\text{eq}}$
O1	0.1853 (5)	0.6350 (2)	1.0622 (2)	0.0353 (7)
C2	0.1680 (7)	0.6538 (4)	1.1434 (3)	0.0408 (11)
N3	0.1585 (6)	0.7463 (3)	1.1614 (2)	0.0430 (10)
C4	0.1733 (6)	0.7940 (4)	1.0879 (3)	0.0344 (10)
C5	0.1745 (8)	0.8991 (4)	1.0713 (3)	0.0347 (11)
N6	0.1944 (5)	0.9220 (3)	0.9912 (2)	0.0311 (8)
C7	0.2122 (7)	0.8525 (3)	0.9299 (3)	0.0261 (10)
N8	0.2338 (5)	0.8876 (3)	0.8560 (3)	0.0324 (8)
C9	0.2503 (6)	0.8216 (4)	0.7968 (3)	0.0352 (10)
H9	0.2659	0.8454	0.7438	0.042*
C10	0.2456 (6)	0.7205 (3)	0.8090 (3)	0.0327 (10)
C11	0.2253 (6)	0.6834 (3)	0.8840 (3)	0.0299 (9)
H11	0.2232	0.6140	0.8929	0.036*
C12	0.2078 (6)	0.7493 (3)	0.9470 (2)	0.0269 (9)
C13	0.1890 (6)	0.7265 (3)	1.0287 (3)	0.0299 (9)
C14	0.1651 (9)	0.5668 (5)	1.1959 (4)	0.0590 (16)
H14A	0.1328	0.5876	1.2504	0.089*
H14B	0.2962	0.5350	1.1953	0.089*
H14C	0.0643	0.5199	1.1770	0.089*
O15	0.1582 (6)	0.9635 (3)	1.1226 (2)	0.0501 (9)
Br16	0.26869 (6)	0.63431 (3)	0.72061 (4)	0.04509 (16)
C17	0.2032 (7)	1.0293 (3)	0.9709 (3)	0.0359 (10)
H17A	0.2912	1.0383	0.9241	0.043*
H17B	0.2634	1.0656	1.0163	0.043*
C18	0.0019 (6)	1.0740 (3)	0.9526 (3)	0.0360 (10)
C19	-0.1165 (8)	1.1102 (4)	1.0132 (4)	0.0456 (13)
H19	-0.0752	1.1033	1.0671	0.055*
C20	-0.2946 (10)	1.1562 (5)	0.9957 (5)	0.0567 (18)
H20	-0.3748	1.1810	1.0379	0.068*
C21	-0.3576 (8)	1.1669 (4)	0.9187 (4)	0.0534 (15)
H21	-0.4804	1.1990	0.9075	0.064*
C22	-0.2419 (8)	1.1307 (4)	0.8573 (4)	0.0514 (16)
H22	-0.2840	1.1380	0.8035	0.062*
C23	-0.0632 (8)	1.0834 (4)	0.8746 (3)	0.0476 (13)
H23	0.0152	1.0572	0.8324	0.057*

*Atomic displacement parameters (Å<sup>2</sup>)*

	$U^{11}$	$U^{22}$	$U^{33}$	$U^{12}$	$U^{13}$	$U^{23}$
O1	0.0308 (15)	0.0340 (17)	0.0412 (18)	0.0005 (12)	-0.0015 (14)	0.0023 (14)
C2	0.029 (2)	0.053 (3)	0.040 (3)	0.003 (2)	-0.001 (2)	0.006 (2)
N3	0.031 (2)	0.060 (3)	0.037 (2)	0.0057 (18)	-0.0035 (18)	-0.001 (2)
C4	0.022 (2)	0.043 (3)	0.038 (3)	0.006 (2)	-0.0047 (19)	-0.008 (2)
C5	0.028 (3)	0.039 (3)	0.037 (3)	0.001 (2)	-0.008 (2)	-0.012 (2)
N6	0.0261 (17)	0.0250 (18)	0.042 (2)	-0.0009 (15)	0.0004 (16)	-0.0089 (16)
C7	0.018 (2)	0.028 (2)	0.033 (2)	-0.0013 (18)	0.0012 (19)	-0.0084 (19)
N8	0.0262 (17)	0.030 (2)	0.041 (2)	0.0006 (14)	0.0026 (16)	-0.0028 (17)
C9	0.028 (2)	0.042 (3)	0.035 (2)	0.0009 (19)	0.0039 (19)	-0.006 (2)
C10	0.022 (2)	0.034 (2)	0.042 (2)	-0.0003 (17)	0.0011 (18)	-0.0154 (19)
C11	0.022 (2)	0.027 (2)	0.041 (2)	0.0004 (18)	-0.0027 (18)	-0.0099 (19)
C12	0.0164 (19)	0.027 (2)	0.037 (2)	-0.0007 (15)	-0.0006 (17)	-0.0069 (18)
C13	0.0204 (19)	0.027 (2)	0.043 (3)	0.0006 (16)	-0.0016 (18)	-0.0008 (18)
C14	0.053 (3)	0.072 (4)	0.053 (3)	0.006 (3)	-0.003 (2)	0.022 (3)
O15	0.057 (2)	0.049 (2)	0.044 (2)	0.0047 (18)	-0.0070 (18)	-0.0256 (17)
Br16	0.0427 (2)	0.0502 (3)	0.0424 (2)	-0.0015 (2)	0.0038 (4)	-0.0214 (3)
C17	0.036 (2)	0.023 (2)	0.049 (3)	-0.0021 (17)	0.002 (2)	-0.011 (2)
C18	0.035 (2)	0.020 (2)	0.052 (3)	-0.0044 (17)	0.002 (2)	-0.002 (2)
C19	0.045 (3)	0.038 (3)	0.054 (3)	0.007 (2)	0.011 (3)	0.002 (2)
C20	0.049 (4)	0.043 (3)	0.078 (5)	0.013 (3)	0.014 (4)	0.008 (3)
C21	0.037 (3)	0.032 (3)	0.092 (5)	0.001 (2)	-0.009 (3)	0.007 (3)
C22	0.056 (4)	0.040 (3)	0.058 (4)	-0.010 (3)	-0.011 (3)	0.006 (2)
C23	0.053 (3)	0.033 (3)	0.056 (3)	-0.003 (2)	0.003 (3)	-0.003 (2)

*Geometric parameters (Å, °)*

O1—C2	1.389 (6)	C11—C12	1.386 (6)
O1—C13	1.358 (5)	C12—C13	1.408 (6)
C2—N3	1.287 (6)	C14—H14A	0.9800
C2—C14	1.467 (7)	C14—H14B	0.9800
N3—C4	1.393 (6)	C14—H14C	0.9800
C4—C5	1.446 (7)	C17—H17A	0.9900
C4—C13	1.352 (6)	C17—H17B	0.9900
C5—N6	1.384 (7)	C17—C18	1.512 (6)
C5—O15	1.229 (6)	C18—C19	1.379 (7)
N6—C7	1.396 (6)	C18—C23	1.383 (7)
N6—C17	1.489 (6)	C19—H19	0.9500
C7—N8	1.335 (7)	C19—C20	1.380 (9)
C7—C12	1.423 (6)	C20—H20	0.9500
N8—C9	1.338 (6)	C20—C21	1.365 (10)
C9—H9	0.9500	C21—H21	0.9500
C9—C10	1.381 (7)	C21—C22	1.379 (9)
C10—C11	1.359 (7)	C22—H22	0.9500
C10—Br16	1.890 (4)	C22—C23	1.390 (7)
C11—H11	0.9500	C23—H23	0.9500

C13—O1—C2	103.9 (4)	C4—C13—C12	125.0 (4)
O1—C2—C14	116.2 (4)	C2—C14—H14A	109.5
N3—C2—O1	114.3 (4)	C2—C14—H14B	109.5
N3—C2—C14	129.5 (5)	C2—C14—H14C	109.5
C2—N3—C4	103.8 (4)	H14A—C14—H14B	109.5
N3—C4—C5	128.6 (4)	H14A—C14—H14C	109.5
C13—C4—N3	110.1 (4)	H14B—C14—H14C	109.5
C13—C4—C5	121.3 (4)	N6—C17—H17A	108.9
N6—C5—C4	114.0 (4)	N6—C17—H17B	108.9
O15—C5—C4	124.1 (5)	N6—C17—C18	113.6 (3)
O15—C5—N6	121.9 (5)	H17A—C17—H17B	107.7
C5—N6—C7	124.8 (4)	C18—C17—H17A	108.9
C5—N6—C17	116.3 (4)	C18—C17—H17B	108.9
C7—N6—C17	118.9 (4)	C19—C18—C17	120.4 (5)
N6—C7—C12	120.6 (4)	C19—C18—C23	118.8 (5)
N8—C7—N6	116.9 (4)	C23—C18—C17	120.8 (5)
N8—C7—C12	122.5 (4)	C18—C19—H19	119.9
C7—N8—C9	117.4 (4)	C18—C19—C20	120.2 (6)
N8—C9—H9	118.4	C20—C19—H19	119.9
N8—C9—C10	123.1 (5)	C19—C20—H20	119.4
C10—C9—H9	118.4	C21—C20—C19	121.1 (6)
C9—C10—Br16	119.4 (4)	C21—C20—H20	119.4
C11—C10—C9	120.3 (4)	C20—C21—H21	120.2
C11—C10—Br16	120.4 (3)	C20—C21—C22	119.5 (6)
C10—C11—H11	120.8	C22—C21—H21	120.2
C10—C11—C12	118.5 (4)	C21—C22—H22	120.2
C12—C11—H11	120.8	C21—C22—C23	119.5 (6)
C11—C12—C7	118.2 (4)	C23—C22—H22	120.2
C11—C12—C13	127.5 (4)	C18—C23—C22	120.8 (6)
C13—C12—C7	114.3 (4)	C18—C23—H23	119.6
O1—C13—C12	127.1 (4)	C22—C23—H23	119.6
C4—C13—O1	107.9 (4)		
O1—C2—N3—C4	-0.9 (6)	N8—C9—C10—C11	-0.6 (7)
C2—O1—C13—C4	-0.3 (4)	N8—C9—C10—Br16	179.6 (3)
C2—O1—C13—C12	179.0 (4)	C9—C10—C11—C12	0.6 (6)
C2—N3—C4—C5	-179.0 (5)	C10—C11—C12—C7	-0.1 (6)
C2—N3—C4—C13	0.7 (5)	C10—C11—C12—C13	-178.8 (4)
N3—C4—C5—N6	179.1 (4)	C11—C12—C13—O1	0.4 (7)
N3—C4—C5—O15	-1.4 (8)	C11—C12—C13—C4	179.7 (4)
N3—C4—C13—O1	-0.2 (5)	C12—C7—N8—C9	0.5 (6)
N3—C4—C13—C12	-179.6 (4)	C13—O1—C2—N3	0.8 (5)
C4—C5—N6—C7	0.0 (7)	C13—O1—C2—C14	-178.6 (4)
C4—C5—N6—C17	-178.1 (4)	C13—C4—C5—N6	-0.5 (6)
C5—C4—C13—O1	179.5 (4)	C13—C4—C5—O15	179.0 (5)
C5—C4—C13—C12	0.1 (7)	C14—C2—N3—C4	178.4 (5)
C5—N6—C7—N8	-178.8 (4)	O15—C5—N6—C7	-179.5 (5)



C5—N6—C7—C12	0.9 (7)	O15—C5—N6—C17	2.4 (7)
C5—N6—C17—C18	-91.6 (5)	Br16—C10—C11—C12	-179.7 (3)
N6—C7—N8—C9	-179.8 (4)	C17—N6—C7—N8	-0.8 (6)
N6—C7—C12—C11	179.8 (4)	C17—N6—C7—C12	179.0 (4)
N6—C7—C12—C13	-1.3 (6)	C17—C18—C19—C20	176.1 (5)
N6—C17—C18—C19	86.4 (5)	C17—C18—C23—C22	-175.5 (4)
N6—C17—C18—C23	-96.4 (5)	C18—C19—C20—C21	0.1 (9)
C7—N6—C17—C18	90.2 (5)	C19—C18—C23—C22	1.7 (7)
C7—N8—C9—C10	0.1 (6)	C19—C20—C21—C22	0.3 (10)
C7—C12—C13—O1	-178.4 (4)	C20—C21—C22—C23	0.4 (8)
C7—C12—C13—C4	0.9 (6)	C21—C22—C23—C18	-1.4 (8)
N8—C7—C12—C11	-0.5 (6)	C23—C18—C19—C20	-1.1 (7)
N8—C7—C12—C13	178.5 (4)		

*Hydrogen-bond geometry* (Å, °)

Cg3 is the centroid of the C18—C23 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>
C21—H21...Cg3 <sup>i</sup>	0.95	2.82	3.604 (6)	141
C11—H11...Cg3 <sup>ii</sup>	0.95	3.31	4.239 (6)	167

Symmetry codes: (i)  $x-1/2, -y+5/2, z$ ; (ii)  $x+1/2, -y+3/2, z$ .