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# 1-Bromo-2-(10$\beta$-dihydroartemisinoxy)-ethane

**Marli C. Lombard,[a] Manuel A. Fernandes,[b] Jaco C. Breytenbach[a] and David D. N'Da[a]***

[a]Department of Pharmaceutical Chemistry, North-West University, PO NWU 2520, Potchefstroom, South Africa, and [b]Molecular Sciences Institute, School of Chemistry, University of the Witwatersrand, PO Wits 2050, Johannesburg, South Africa
Correspondence e-mail: 13014196@nwu.ac.za

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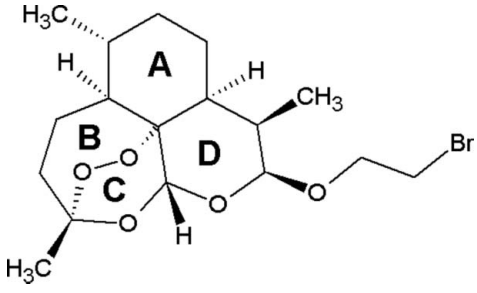
Key indicators: single-crystal X-ray study; $T$ = 173 K; mean $\sigma$(C–C) = 0.003 Å; $R$ factor = 0.034; $wR$ factor = 0.078; data-to-parameter ratio = 19.9.

The title compound, $C_{17}H_{27}BrO_5$, DEB, is a derivative of artemisinin which is used in malara therapy. The OR-group at C12 is *cis* to the $CH_3$-group at C11 and axially oriented on ring *D* which has a chair conformation. The crystal packing is stabilized by several weak intermolecular C—H···O interactions, which combine to form a C—H—O bonded network parallel to (001).

## Related literature

For background to malaria, see: World Health Organisation (2008). For the effective of artemisinin analogs against malaria, see: Ploypradith (2004). For the crystal structure of artemisinin, see: Kuhn & Wang (2008) and of dihydroartemisinin (DHA), see: Luo *et al.* (1984). Jasinski *et al.* (2008*a*) redetermined the structure of DHA as well as characterizing the second polymer of $\beta$-arteether (Jasinski *et al.*, 2008*b*). For the reaction of DEB with amines, see: Li *et al.* (2000). For the synthesis of artemisinin hybrids, see: Walsh *et al.* (2007); Basco *et al.* (2001); Grelepois *et al.* (2005); Gupta *et al.* (2002). For puckering analysis, see: Cremer & Pople (1975); Evans & Boeyens (1989).




## Experimental

### Crystal data

$C_{17}H_{27}BrO_5$
$M_r$ = 391.30
Monoclinic, $P2_1$
$a$ = 9.2836 (2) Å
$b$ = 9.1103 (2) Å
$c$ = 10.2999 (2) Å
$\beta$ = 90.395 (1)°
$V$ = 871.11 (3) Å$^3$
$Z$ = 2
Mo $K\alpha$ radiation
$\mu$ = 2.38 mm$^{-1}$
$T$ = 173 K
0.44 × 0.41 × 0.08 mm

### Data collection

Bruker APEXII CCD diffractometer
Absorption correction: integration (*XPREP*; Bruker, 2005)
$T_{min}$ = 0.420, $T_{max}$ = 0.832
13762 measured reflections
4196 independent reflections
3432 reflections with $I > 2\sigma(I)$
$R_{int}$ = 0.068

### Refinement

$R[F^2 > 2\sigma(F^2)]$ = 0.034
$wR(F^2)$ = 0.078
$S$ = 0.95
4196 reflections
211 parameters
1 restraint
H-atom parameters constrained
$\Delta\rho_{max}$ = 0.61 e Å$^{-3}$
$\Delta\rho_{min}$ = −0.35 e Å$^{-3}$
Absolute structure: Flack (1983), 1966 Friedel pairs
Flack parameter: −0.012 (7)

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

| $D$—H···$A$ | $D$—H | H···$A$ | $D$···$A$ | $D$—H···$A$ |
|---|---|---|---|---|
| C15—H15$B$···O2$^{i}$ | 0.98 | 2.50 | 3.434 (3) | 159 |
| C16—H16$A$···O3$^{ii}$ | 0.99 | 2.46 | 3.285 (3) | 141 |
| C17—H17$B$···O4$^{ii}$ | 0.99 | 2.50 | 3.282 (3) | 136 |

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

Data collection: *APEX2* (Bruker, 2005); cell refinement: *SAINT* (Bruker, 2005); data reduction: *SAINT*; program(s) used to solve structure: *SHELXS97* (Sheldrick, 2008); program(s) used to refine structure: *SHELXL97* (Sheldrick, 2008); molecular graphics: *ORTEP-3 for Windows* (Farrugia, 1997) and *SCHAKAL99* (Keller, 1999); software used to prepare material for publication: *WinGX* (Farrugia, 1999) and *PLATON* (Spek, 2009).

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Supplementary data and figures for this paper are available from the IUCr electronic archives (Reference: JJ2039).

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# supporting information

*Acta Cryst.* (2010). E**66**, o2182–o2183 [https://doi.org/10.1107/S1600536810029090]

## 1-Bromo-2-(10*β*-dihydroartemisinoxy)ethane

**Marli C. Lombard, Manuel A. Fernandes, Jaco C. Breytenbach and David D. N'Da**

### S1. Comment

Malaria is one of the top three priority diseases of the WHO and is becoming a worldwide threat because of its wide spread resistance to current anti-malaria drugs (World Health Organization, 2008). Artemisinin and its derivatives currently represent the most effective group of compounds against multidrug-resistant malaria with a rapid onset of action and a short half life. However, when artemisinin analogs are used as monotherapy it results in significant recrudescence (Ploypradith, 2004). Therefore it is recommended by the WHO that all uncomplicated P. falciparum infections should be treated with an artemisinin-based combination therapy (ACT).

When DHA is prepared from artemisinin by reduction, it exists as a mixture of *α*- and *β*-isomers. Luo and co-workers (Luo *et al.* 1984) determined that these isomers can exist in two conformations of ring D, a half-chair form and a half-boat form. DEB was tested *in vitro* against *Plasmodium falciparum* sensitive (D10) and resistant (Dd2) strains, but did not show any improved activity with respect to the reference drug: dihydroartemisinin (DHA).

The title compound, $C_{17}H_{27}BrO_5$ or 2-(10*β*-dihydroartemisinoxy)ethylbromide (DEB), is a derivative of artemisinin. DEB was synthesized from the reaction of DHA with bromoethanol. DHA was supplied as a mixture of anomers. With the formation of DEB the OR-group at C12 is positioned *cis* to the $CH_3$-group at C11 and axially oriented on ring D. Therefore, DEB can be assigned to the *β*-chair series. The rings in the title compound have also been previously labeled as rings A, B, C and D (scheme). Ring A has a twist boat conformation with puckering parameters (Cremer & Pople, 1975) Q, *θ* and *φ* of 0.739 (2), 94.21 (15)° and 274.46 (16)°, respectively (Fig. 1). Ring B has a distorted boat conformation and ring C is in a slightly distorted chair conformation with puckering parameters Q, *θ* and *φ* of 0.539 (3), 8.6 (3)° and 195.6 (18)°. Ring D is in a chair conformation with puckering parameters Q, *θ* and *φ* of 0.532 (2), 178.2 (3)° and 73 (11)°. Crystal packing in DEB is stabilized by a several C—H···O weak intermolecular interactions (Table 1) some of which are shown in Fig 2. These combine to form a C—H—O bonded network parallel to (001).

### S2. Experimental

The title compound was prepared as described by Li and co-workers (Li *et al.*, 2000). The product was recrystallized from methanol using a slow evaporation technique at room temperature with a 71% yield of white needle-like crystals. $IC_{50}$ (ng/ml) of the title compound (DEB): D10 = 41.39, Dd2 = 129.47 $IC_{50}$ (ng/ml) of Dihydroartemisinin: D10 = 1.45, Dd2 = 0.59.

### S3. Refinement

All H atoms were positioned geometrically, and allowed to ride on their parent atoms, with Atom—H bond lengths of 1.00 Å (CH), 0.99 Å ($CH_2$), or 0.98 Å ($CH_3$). Isotropic displacement parameters for these atoms were set to 1.2 times (CH and $CH_2$) or 1.5 times ($CH_3$) $U_{eq}$ of the parent atom.

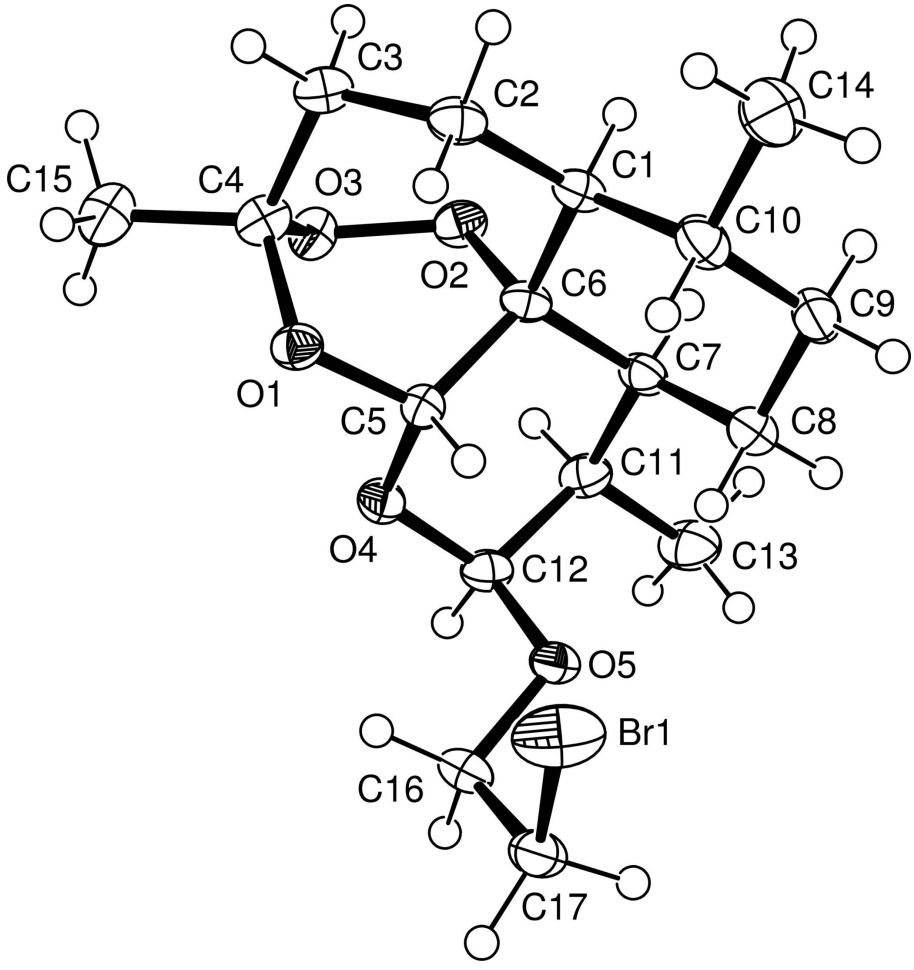


**Figure 1**

The molecular structure of $C_{17}H_{27}BrO_5$ (DEB), showing the atomic numbering scheme. Displacement ellipsoids are drawn at the 50% probability level.

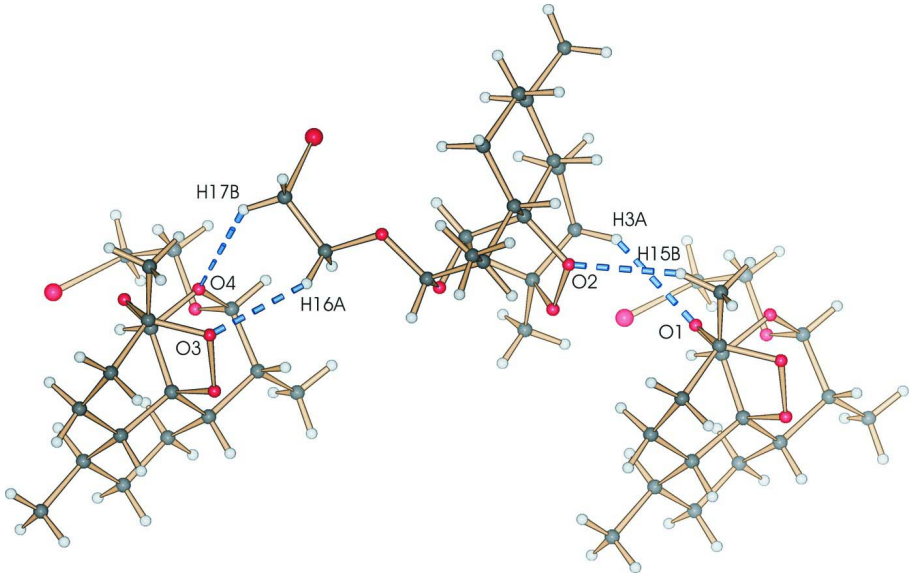


**Figure 2**

Packing diagram of $C_{17}H_{27}BrO_5$ showing the weak intermolecular C—H···O hydrogen bonding network where chains of molecules run parallel to (001).

### 1-Bromo-2-(10*β*-dihydroartemisinoxy)ethane

*Crystal data*

$C_{17}H_{27}BrO_5$
$M_r = 391.30$
Monoclinic, $P2_1$
Hall symbol: P 2yb
$a = 9.2836\ (2)$ Å
$b = 9.1103\ (2)$ Å
$c = 10.2999\ (2)$ Å
$\beta = 90.395\ (1)°$
$V = 871.11\ (3)$ Å$^3$
$Z = 2$
$F(000) = 408$
$D_x = 1.492$ Mg m$^{-3}$
Mo $K\alpha$ radiation, $\lambda = 0.71073$ Å
Cell parameters from 6155 reflections
$\theta = 2.9–28.2°$
$\mu = 2.38$ mm$^{-1}$
$T = 173$ K
Plate, colourless
0.44 × 0.41 × 0.08 mm

*Data collection*

Bruker APEXII CCD diffractometer
Radiation source: fine-focus sealed tube
Graphite monochromator
$\varphi$ and $\omega$ scans
Absorption correction: integration (*XPREP*; Bruker, 2005)
$T_{min} = 0.420$, $T_{max} = 0.832$
13762 measured reflections
4196 independent reflections
3432 reflections with $I > 2\sigma(I)$
$R_{int} = 0.068$
$\theta_{max} = 28.0°$, $\theta_{min} = 2.0°$
$h = -12\rightarrow12$
$k = -12\rightarrow12$
$l = -13\rightarrow13$

*Refinement*

Refinement on $F^2$
Least-squares matrix: full
$R[F^2 > 2\sigma(F^2)] = 0.034$
$wR(F^2) = 0.078$
$S = 0.95$
4196 reflections
211 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
$w = 1/[\sigma^2(F_o^2) + (0.0405P)^2]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{max} = 0.001$
$\Delta\rho_{max} = 0.61$ e Å$^{-3}$
$\Delta\rho_{min} = -0.35$ e Å$^{-3}$
Absolute structure: Flack (1983), 1966 Friedel pairs
Absolute structure parameter: −0.012 (7)

*Special details*

**Experimental**. $^1$H NMR (600.17 MHz; $CDCl_3$; $Me_4Si$): $\delta_H$ 5.46 (s, 1H, H-5), 4.82 (d, J = 3.4 Hz, 1H, H-12), 4.09 (ddd, J = 11.8, 6.6, 5.5 Hz, 1H, H-16$\alpha$), 3.79 – 3.73 (m, 1H, H-16$\beta$), 3.51 – 3.47 (m, 2H, H-17), 2.66 – 2.59 (m, 1H, H-11), 2.39 – 2.30 (m, 1H, H-3$\alpha$), 2.01 (ddd, J = 14.6, 4.7, 3.1 Hz, 1H, H-3$\beta$), 1.92 – 1.81 (m, 2H, H-2$\alpha$; H-8$\alpha$), 1.73 (ddd, J = 14.2, 7.7, 3.6 Hz, 1H, H-8$\beta$), 1.62 (dq, J = 13.2, 3.3 Hz, 1H, H-9$\beta$), 1.47 (qdd, J = 12.0, 8.9, 4.1 Hz, 2H, H-2$\alpha$; H-7), 1.41 (s, 3H, H-15), 1.36 – 1.28 (m, 1H, H-10), 1.22 (td, J = 11.5, 6.6 Hz, 1H, H-1), 0.93 (d, J = 6.4 Hz, 3H, H-13), 0.91 (d, J = 7.4 Hz, 3H, H-14), 0.87 (dd, J = 13.3, 3.6 Hz, 3H, H-9$\alpha$). $^{13}$C NMR (150.913 MHz; $CDCl_3$; $Me_4Si$): $\delta_C$ 104.10 (C-4), 102.02 (C-12), 88.12 (C-5), 81.07 (C-6), 68.14 (C-16), 52.54 (C-1), 44.33 (C-7), 37.36 (C-10), 36.37 (C-3), 34.63 (C-11), 31.41 (C-17), 30.86 (C-11), 26.12 (C-15), 24.62 (C-2), 24.33 (C-8), 20.34 (C-14), 12.95 (C-13).

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

| | *x* | *y* | *z* | $U_{iso}$*/$U_{eq}$ |
|---|---|---|---|---|
| C1 | 0.4624 (2) | 0.8858 (2) | 0.7096 (2) | 0.0219 (6) |
| H1 | 0.4971 | 0.9825 | 0.6759 | 0.026* |
| C2 | 0.5821 (3) | 0.8288 (3) | 0.8003 (2) | 0.0240 (5) |
| H2A | 0.5667 | 0.7224 | 0.8142 | 0.029* |
| H2B | 0.6756 | 0.8404 | 0.7558 | 0.029* |
| C3 | 0.5930 (2) | 0.9028 (3) | 0.9323 (2) | 0.0254 (5) |
| H3A | 0.6188 | 1.0072 | 0.9196 | 0.030* |
| H3B | 0.6717 | 0.8561 | 0.9828 | 0.030* |
| C4 | 0.4535 (2) | 0.8946 (3) | 1.0112 (2) | 0.0236 (6) |
| C5 | 0.2721 (2) | 0.7966 (3) | 0.8734 (2) | 0.0193 (5) |
| H5 | 0.2584 | 0.7047 | 0.8217 | 0.023* |
| C6 | 0.3193 (2) | 0.9184 (3) | 0.7817 (2) | 0.0199 (4) |
| C7 | 0.1958 (2) | 0.9600 (3) | 0.6879 (2) | 0.0221 (5) |
| H7 | 0.2231 | 1.0558 | 0.6476 | 0.027* |
| C8 | 0.1822 (3) | 0.8494 (3) | 0.5770 (2) | 0.0293 (6) |
| H8A | 0.1553 | 0.7523 | 0.6126 | 0.035* |
| H8B | 0.1046 | 0.8812 | 0.5168 | 0.035* |
| C9 | 0.3227 (3) | 0.8356 (3) | 0.5027 (2) | 0.0286 (6) |
| H9A | 0.3101 | 0.7640 | 0.4312 | 0.034* |
| H9B | 0.3472 | 0.9317 | 0.4638 | 0.034* |
| C10 | 0.4453 (3) | 0.7860 (3) | 0.5903 (2) | 0.0268 (6) |
| H10 | 0.4230 | 0.6847 | 0.6215 | 0.032* |
| C11 | 0.0559 (3) | 0.9877 (3) | 0.7641 (2) | 0.0246 (5) |

| | | | | |
|---|---|---|---|---|
| H11 | 0.0758 | 1.0741 | 0.8214 | 0.030* |
| C12 | 0.0223 (3) | 0.8610 (3) | 0.8544 (2) | 0.0230 (5) |
| H12 | −0.0616 | 0.8898 | 0.9092 | 0.028* |
| C13 | −0.0724 (3) | 1.0314 (3) | 0.6780 (3) | 0.0347 (6) |
| H13A | −0.1037 | 0.9465 | 0.6266 | 0.052* |
| H13B | −0.0436 | 1.1110 | 0.6196 | 0.052* |
| H13C | −0.1520 | 1.0647 | 0.7327 | 0.052* |
| C14 | 0.5866 (3) | 0.7794 (4) | 0.5130 (3) | 0.0378 (7) |
| H14A | 0.5710 | 0.7232 | 0.4331 | 0.057* |
| H14B | 0.6613 | 0.7317 | 0.5658 | 0.057* |
| H14C | 0.6173 | 0.8792 | 0.4911 | 0.057* |
| C15 | 0.4802 (3) | 0.8852 (3) | 1.1564 (2) | 0.0318 (7) |
| H15A | 0.5460 | 0.9638 | 1.1832 | 0.048* |
| H15B | 0.5231 | 0.7898 | 1.1776 | 0.048* |
| H15C | 0.3886 | 0.8959 | 1.2022 | 0.048* |
| C16 | −0.0657 (3) | 0.6166 (3) | 0.8603 (2) | 0.0281 (6) |
| H16A | −0.1615 | 0.6395 | 0.8966 | 0.034* |
| H16B | 0.0026 | 0.6017 | 0.9333 | 0.034* |
| C17 | −0.0743 (3) | 0.4798 (3) | 0.7792 (3) | 0.0290 (6) |
| H17A | −0.1326 | 0.4995 | 0.7003 | 0.035* |
| H17B | −0.1227 | 0.4014 | 0.8292 | 0.035* |
| Br1 | 0.11699 (3) | 0.41341 (4) | 0.72890 (3) | 0.04547 (10) |
| O1 | 0.37137 (18) | 0.76784 (19) | 0.97365 (16) | 0.0221 (4) |
| O2 | 0.34641 (18) | 1.05261 (18) | 0.85662 (16) | 0.0241 (4) |
| O3 | 0.3660 (2) | 1.02082 (18) | 0.99572 (17) | 0.0234 (4) |
| O4 | 0.13965 (17) | 0.82985 (18) | 0.93755 (15) | 0.0225 (4) |
| O5 | −0.01788 (17) | 0.73579 (18) | 0.78053 (15) | 0.0235 (4) |

*Atomic displacement parameters (Å²)*

| | $U^{11}$ | $U^{22}$ | $U^{33}$ | $U^{12}$ | $U^{13}$ | $U^{23}$ |
|---|---|---|---|---|---|---|
| C1 | 0.0195 (11) | 0.0211 (16) | 0.0252 (11) | −0.0027 (9) | 0.0061 (9) | 0.0001 (10) |
| C2 | 0.0186 (12) | 0.0237 (12) | 0.0298 (13) | 0.0011 (10) | 0.0059 (10) | −0.0033 (11) |
| C3 | 0.0193 (10) | 0.0246 (12) | 0.0322 (12) | −0.0011 (13) | 0.0004 (9) | −0.0026 (14) |
| C4 | 0.0208 (11) | 0.0207 (15) | 0.0292 (12) | 0.0039 (11) | −0.0004 (9) | −0.0050 (11) |
| C5 | 0.0199 (12) | 0.0195 (12) | 0.0185 (12) | −0.0010 (10) | −0.0003 (10) | 0.0001 (10) |
| C6 | 0.0187 (9) | 0.0162 (9) | 0.0250 (11) | −0.0016 (13) | 0.0032 (8) | −0.0007 (13) |
| C7 | 0.0211 (11) | 0.0202 (12) | 0.0250 (13) | −0.0024 (9) | 0.0015 (10) | 0.0066 (10) |
| C8 | 0.0266 (14) | 0.0357 (13) | 0.0255 (13) | −0.0069 (11) | 0.0003 (11) | 0.0059 (12) |
| C9 | 0.0343 (15) | 0.0308 (14) | 0.0206 (13) | −0.0052 (11) | 0.0046 (11) | 0.0010 (11) |
| C10 | 0.0322 (14) | 0.0241 (12) | 0.0243 (13) | −0.0034 (11) | 0.0078 (11) | −0.0021 (11) |
| C11 | 0.0199 (12) | 0.0233 (12) | 0.0307 (14) | −0.0003 (10) | −0.0024 (11) | 0.0005 (11) |
| C12 | 0.0174 (11) | 0.0239 (11) | 0.0277 (13) | −0.0015 (9) | 0.0029 (10) | −0.0020 (10) |
| C13 | 0.0219 (13) | 0.0359 (16) | 0.0463 (17) | 0.0016 (11) | −0.0030 (12) | 0.0072 (14) |
| C14 | 0.0356 (16) | 0.0446 (17) | 0.0331 (15) | 0.0036 (13) | 0.0099 (13) | −0.0098 (13) |
| C15 | 0.0280 (12) | 0.0380 (19) | 0.0294 (13) | 0.0083 (11) | −0.0025 (10) | −0.0077 (12) |
| C16 | 0.0265 (13) | 0.0291 (14) | 0.0287 (14) | −0.0081 (10) | 0.0059 (11) | 0.0050 (11) |
| C17 | 0.0243 (12) | 0.0301 (13) | 0.0326 (14) | −0.0061 (11) | 0.0003 (11) | 0.0075 (11) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Br1 | 0.03348 (15) | 0.03086 (14) | 0.0721 (2) | 0.00014 (15) | 0.00489 (12) | −0.00932 (17) |
| O1 | 0.0188 (9) | 0.0213 (9) | 0.0262 (10) | 0.0004 (7) | −0.0008 (7) | 0.0009 (8) |
| O2 | 0.0249 (9) | 0.0177 (8) | 0.0296 (10) | −0.0009 (7) | −0.0010 (8) | −0.0022 (7) |
| O3 | 0.0239 (9) | 0.0236 (10) | 0.0228 (9) | 0.0051 (7) | 0.0001 (7) | −0.0055 (8) |
| O4 | 0.0188 (8) | 0.0270 (9) | 0.0219 (8) | −0.0001 (7) | 0.0026 (7) | 0.0006 (7) |
| O5 | 0.0195 (8) | 0.0254 (9) | 0.0255 (9) | −0.0045 (7) | 0.0014 (7) | 0.0030 (7) |

*Geometric parameters (Å, º)*

| | | | |
|---|---|---|---|
| C1—C10 | 1.536 (3) | C9—H9B | 0.9900 |
| C1—C2 | 1.538 (3) | C10—C14 | 1.539 (3) |
| C1—C6 | 1.556 (3) | C10—H10 | 1.0000 |
| C1—H1 | 1.0000 | C11—C12 | 1.515 (3) |
| C2—C3 | 1.520 (3) | C11—C13 | 1.533 (4) |
| C2—H2A | 0.9900 | C11—H11 | 1.0000 |
| C2—H2B | 0.9900 | C12—O4 | 1.410 (3) |
| C3—C4 | 1.535 (3) | C12—O5 | 1.420 (3) |
| C3—H3A | 0.9900 | C12—H12 | 1.0000 |
| C3—H3B | 0.9900 | C13—H13A | 0.9800 |
| C4—O3 | 1.416 (3) | C13—H13B | 0.9800 |
| C4—O1 | 1.435 (3) | C13—H13C | 0.9800 |
| C4—C15 | 1.517 (3) | C14—H14A | 0.9800 |
| C5—O1 | 1.404 (3) | C14—H14B | 0.9800 |
| C5—O4 | 1.433 (3) | C14—H14C | 0.9800 |
| C5—C6 | 1.523 (3) | C15—H15A | 0.9800 |
| C5—H5 | 1.0000 | C15—H15B | 0.9800 |
| C6—O2 | 1.467 (3) | C15—H15C | 0.9800 |
| C6—C7 | 1.541 (3) | C16—O5 | 1.434 (3) |
| C7—C8 | 1.528 (4) | C16—C17 | 1.502 (4) |
| C7—C11 | 1.543 (4) | C16—H16A | 0.9900 |
| C7—H7 | 1.0000 | C16—H16B | 0.9900 |
| C8—C9 | 1.522 (4) | C17—Br1 | 1.949 (3) |
| C8—H8A | 0.9900 | C17—H17A | 0.9900 |
| C8—H8B | 0.9900 | C17—H17B | 0.9900 |
| C9—C10 | 1.517 (4) | O2—O3 | 1.472 (2) |
| C9—H9A | 0.9900 | | |

| | | | |
|---|---|---|---|
| C10—C1—C2 | 110.89 (19) | C9—C10—C1 | 111.9 (2) |
| C10—C1—C6 | 114.27 (19) | C9—C10—C14 | 110.0 (2) |
| C2—C1—C6 | 112.98 (18) | C1—C10—C14 | 110.7 (2) |
| C10—C1—H1 | 106.0 | C9—C10—H10 | 108.0 |
| C2—C1—H1 | 106.0 | C1—C10—H10 | 108.0 |
| C6—C1—H1 | 106.0 | C14—C10—H10 | 108.0 |
| C3—C2—C1 | 115.91 (19) | C12—C11—C13 | 113.0 (2) |
| C3—C2—H2A | 108.3 | C12—C11—C7 | 111.41 (19) |
| C1—C2—H2A | 108.3 | C13—C11—C7 | 113.7 (2) |
| C3—C2—H2B | 108.3 | C12—C11—H11 | 106.0 |
| C1—C2—H2B | 108.3 | C13—C11—H11 | 106.0 |

| | | | |
|---|---|---|---|
| H2A—C2—H2B | 107.4 | C7—C11—H11 | 106.0 |
| C2—C3—C4 | 113.6 (2) | O4—C12—O5 | 111.26 (19) |
| C2—C3—H3A | 108.8 | O4—C12—C11 | 111.38 (19) |
| C4—C3—H3A | 108.8 | O5—C12—C11 | 109.76 (19) |
| C2—C3—H3B | 108.8 | O4—C12—H12 | 108.1 |
| C4—C3—H3B | 108.8 | O5—C12—H12 | 108.1 |
| H3A—C3—H3B | 107.7 | C11—C12—H12 | 108.1 |
| O3—C4—O1 | 108.64 (17) | C11—C13—H13A | 109.5 |
| O3—C4—C15 | 104.26 (19) | C11—C13—H13B | 109.5 |
| O1—C4—C15 | 107.6 (2) | H13A—C13—H13B | 109.5 |
| O3—C4—C3 | 112.7 (2) | C11—C13—H13C | 109.5 |
| O1—C4—C3 | 110.2 (2) | H13A—C13—H13C | 109.5 |
| C15—C4—C3 | 113.08 (19) | H13B—C13—H13C | 109.5 |
| O1—C5—O4 | 105.13 (17) | C10—C14—H14A | 109.5 |
| O1—C5—C6 | 113.71 (18) | C10—C14—H14B | 109.5 |
| O4—C5—C6 | 112.52 (18) | H14A—C14—H14B | 109.5 |
| O1—C5—H5 | 108.4 | C10—C14—H14C | 109.5 |
| O4—C5—H5 | 108.4 | H14A—C14—H14C | 109.5 |
| C6—C5—H5 | 108.4 | H14B—C14—H14C | 109.5 |
| O2—C6—C5 | 109.27 (16) | C4—C15—H15A | 109.5 |
| O2—C6—C7 | 104.4 (2) | C4—C15—H15B | 109.5 |
| C5—C6—C7 | 110.62 (18) | H15A—C15—H15B | 109.5 |
| O2—C6—C1 | 105.43 (17) | C4—C15—H15C | 109.5 |
| C5—C6—C1 | 114.0 (2) | H15A—C15—H15C | 109.5 |
| C7—C6—C1 | 112.44 (17) | H15B—C15—H15C | 109.5 |
| C8—C7—C6 | 111.4 (2) | O5—C16—C17 | 109.00 (18) |
| C8—C7—C11 | 115.0 (2) | O5—C16—H16A | 109.9 |
| C6—C7—C11 | 110.25 (19) | C17—C16—H16A | 109.9 |
| C8—C7—H7 | 106.6 | O5—C16—H16B | 109.9 |
| C6—C7—H7 | 106.6 | C17—C16—H16B | 109.9 |
| C11—C7—H7 | 106.6 | H16A—C16—H16B | 108.3 |
| C9—C8—C7 | 111.3 (2) | C16—C17—Br1 | 111.10 (18) |
| C9—C8—H8A | 109.4 | C16—C17—H17A | 109.4 |
| C7—C8—H8A | 109.4 | Br1—C17—H17A | 109.4 |
| C9—C8—H8B | 109.4 | C16—C17—H17B | 109.4 |
| C7—C8—H8B | 109.4 | Br1—C17—H17B | 109.4 |
| H8A—C8—H8B | 108.0 | H17A—C17—H17B | 108.0 |
| C10—C9—C8 | 111.6 (2) | C5—O1—C4 | 113.13 (18) |
| C10—C9—H9A | 109.3 | C6—O2—O3 | 111.59 (16) |
| C8—C9—H9A | 109.3 | C4—O3—O2 | 109.64 (16) |
| C10—C9—H9B | 109.3 | C12—O4—C5 | 115.10 (17) |
| C8—C9—H9B | 109.3 | C12—O5—C16 | 112.52 (17) |
| H9A—C9—H9B | 108.0 | | |

| | | | |
|---|---|---|---|
| C10—C1—C2—C3 | −170.2 (2) | C2—C1—C10—C14 | −59.8 (3) |
| C6—C1—C2—C3 | −40.4 (3) | C6—C1—C10—C14 | 171.1 (2) |
| C1—C2—C3—C4 | 57.3 (3) | C8—C7—C11—C12 | 75.3 (3) |
| C2—C3—C4—O3 | −94.8 (3) | C6—C7—C11—C12 | −51.6 (3) |

| | | | |
|---|---|---|---|
| C2—C3—C4—O1 | 26.8 (3) | C8—C7—C11—C13 | −53.7 (3) |
| C2—C3—C4—C15 | 147.3 (2) | C6—C7—C11—C13 | 179.4 (2) |
| O1—C5—C6—O2 | −56.7 (2) | C13—C11—C12—O4 | −176.3 (2) |
| O4—C5—C6—O2 | 62.7 (2) | C7—C11—C12—O4 | 54.3 (3) |
| O1—C5—C6—C7 | −171.20 (19) | C13—C11—C12—O5 | 60.0 (3) |
| O4—C5—C6—C7 | −51.8 (3) | C7—C11—C12—O5 | −69.4 (2) |
| O1—C5—C6—C1 | 60.9 (2) | O5—C16—C17—Br1 | 68.7 (2) |
| O4—C5—C6—C1 | −179.69 (19) | O4—C5—O1—C4 | −93.8 (2) |
| C10—C1—C6—O2 | −159.21 (19) | C6—C5—O1—C4 | 29.7 (3) |
| C2—C1—C6—O2 | 72.8 (2) | O3—C4—O1—C5 | 32.8 (2) |
| C10—C1—C6—C5 | 80.9 (2) | C15—C4—O1—C5 | 145.10 (19) |
| C2—C1—C6—C5 | −47.1 (3) | C3—C4—O1—C5 | −91.2 (2) |
| C10—C1—C6—C7 | −46.0 (3) | C5—C6—O2—O3 | 18.1 (2) |
| C2—C1—C6—C7 | −174.0 (2) | C7—C6—O2—O3 | 136.50 (16) |
| O2—C6—C7—C8 | 163.64 (17) | C1—C6—O2—O3 | −104.81 (18) |
| C5—C6—C7—C8 | −78.9 (2) | O1—C4—O3—O2 | −72.2 (2) |
| C1—C6—C7—C8 | 49.8 (3) | C15—C4—O3—O2 | 173.27 (17) |
| O2—C6—C7—C11 | −67.5 (2) | C3—C4—O3—O2 | 50.3 (2) |
| C5—C6—C7—C11 | 50.0 (3) | C6—O2—O3—C4 | 42.6 (2) |
| C1—C6—C7—C11 | 178.7 (2) | O5—C12—O4—C5 | 65.7 (2) |
| C6—C7—C8—C9 | −56.9 (3) | C11—C12—O4—C5 | −57.1 (2) |
| C11—C7—C8—C9 | 176.8 (2) | O1—C5—O4—C12 | −179.24 (18) |
| C7—C8—C9—C10 | 59.5 (3) | C6—C5—O4—C12 | 56.5 (2) |
| C8—C9—C10—C1 | −54.3 (3) | O4—C12—O5—C16 | 62.4 (2) |
| C8—C9—C10—C14 | −177.7 (2) | C11—C12—O5—C16 | −173.86 (19) |
| C2—C1—C10—C9 | 177.06 (19) | C17—C16—O5—C12 | −167.5 (2) |
| C6—C1—C10—C9 | 48.0 (3) | | |

*Hydrogen-bond geometry (Å, º)*

| *D*—H···*A* | *D*—H | H···*A* | *D*···*A* | *D*—H···*A* |
|---|---|---|---|---|
| C15—H15*B*···O2$^{i}$ | 0.98 | 2.50 | 3.434 (3) | 159 |
| C16—H16*A*···O3$^{ii}$ | 0.99 | 2.46 | 3.285 (3) | 141 |
| C17—H17*B*···O4$^{ii}$ | 0.99 | 2.50 | 3.282 (3) | 136 |

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