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# Bispuupehenone from the South Chinese Sea sponge *Dysidea* sp.

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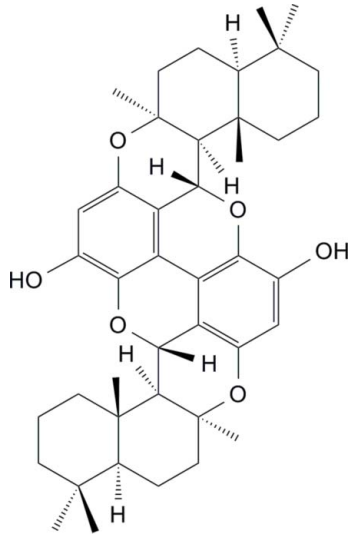
Key indicators: single-crystal X-ray study; $T$ = 293 K; mean $\sigma$(C–C) = 0.004 Å; $R$ factor = 0.045; $wR$ factor = 0.113; data-to-parameter ratio = 9.9.

Bispuupehenone, $C_{42}H_{54}O_6$, formally results from dimerization of puupehenone, which is constructed of sesquiterpene and benzene units. Bispuupehenone was isolated from the South China Sea sponge *Dysidea* sp. and the single-crystal X-ray diffraction analysis confirmed the previously reported structure. The molecule is located on a twofold axis and the dimerization forms two fused dibenzopyran systems related by symmetry. In the asymmetric unit, the two cyclohexane rings adopt chair conformations, while the two pyran rings adopt half-chair conformations. The relative stereochemistry and configurations for the ring junctions are in agreement with the structure reported previously.

## Related literature

The title compound was first isolated from the Pacific marine sponge *Heteronema* sp., see Amade *et al.* (1983). For the biological and pharmaceutical activity of puupehenone, see: Barrero *et al.* (1998, 1999); Castro *et al.* (2004); Ciavatta *et al.* (2007); Longley *et al.* (1993); Kohmoto *et al.* (1987); Takamatsu *et al.* (2003). For the synthesis and semi-synthesis of puupehenone and its derivatives, see: Hamann (2003); Alvarez-Manzaneda *et al.* (2005, 2007).




## Experimental

### Crystal data

$C_{42}H_{54}O_6$
$M_r$ = 654.85
Tetragonal, $P4_12_12$
$a$ = 13.5981 (10) Å
$c$ = 18.7260 (19) Å
$V$ = 3462.6 (5) Å$^3$
$Z$ = 4
Mo $K\alpha$ radiation
$\mu$ = 0.08 mm$^{-1}$
$T$ = 293 (2) K
0.39 × 0.24 × 0.14 mm

### Data collection

Bruker APEX CCD area-detector diffractometer
Absorption correction: multi-scan (*SADABS*; Bruker, 2000)
$T_{min}$ = 0.743, $T_{max}$ = 0.990
20532 measured reflections
2219 independent reflections
1644 reflections with $I > 2\sigma(I)$
$R_{int}$ = 0.110

### Refinement

$R[F^2 > 2\sigma(F^2)]$ = 0.045
$wR(F^2)$ = 0.113
$S$ = 0.94
2219 reflections
225 parameters
H atoms treated by a mixture of independent and constrained refinement
$\Delta\rho_{max}$ = 0.23 e Å$^{-3}$
$\Delta\rho_{min}$ = −0.20 e Å$^{-3}$

Data collection: *SMART* (Bruker, 2000); cell refinement: *SAINT* (Bruker, 2000); data reduction: *SAINT*; program(s) used to solve structure: *SHELXS97* (Sheldrick, 2008); program(s) used to refine structure: *SHELXL97* (Sheldrick, 2008); molecular graphics: *SHELXTL* (Sheldrick, 2008); software used to prepare material for publication: *SHELXTL*.

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Supplementary data and figures for this paper are available from the IUCr electronic archives (Reference: BH2164).

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# supporting information

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## Bispuupehenone from the South Chinese Sea sponge *Dysidea* sp.

**Song Qin, Lei Shi, Jia Li and Yue-Wei Guo**

### S1. Comment

Bispuupehenone (I) was firstly isolated from Pacific marine sponge *Heteronema sp*. (Amade *et al.*, 1983), and was considered to be generated from co-occurring puupehenone (II) (Fig. 1) by *in vitro* oxidative coupling. The benzopyrane structure for the dimer is deduced by the comparison of its UV spectrum data with those of a simple dibenzofuran and a simple benzopyran. Although compound (II) and its derivatives have been reported to display a wide range of important biological activities, including antiviral, antifungal, antimalarial, and antitumor activities (Barrero *et al.*, 1998, 1999; Longley *et al.*, 1993; Castro *et al.*, 2004; Ciavatta *et al.*, 2007; Kohmoto *et al.*, 1987; Takamatsu *et al.*, 2003), the biological properties of (I) have been seldom reported. Synthesis and semi-synthesis of puupehenone and its derivatives have been published (Hamann, 2003); Alvarez-Manzaneda *et al.*, 2005, 2007).

As part of our research project on the study of the South China Sea marine organisms, a sample of the sponge *Dysidea sp*. was collected off the Lingshui Bay, Hainan Province, China, and was chemically investigated. Bispuupehenone, (I), was isolated and crystallized from the $Et_2O$-soluble fraction of the acetone extract of the animal, and the structure of (I) was firstly elucidated by spectroscopic methods, NMR, UV and MS, and eventually confirmed through X-ray diffraction analysis. Herein, we report the X-ray structure of (I).

The projection of bispuupehenone is shown in Figure 2. In the structure, two puupehenone moieties are connected through two O atoms and a C—C bond between benzene rings, forming a benzopyran moiety at the midpoint of the axial symmetric molecule. Rings A and B of (I) are in chair conformations, while rings *C* and *D* adopt half-chair conformations. Moreover, the *trans* junction between rings *A*/*B* and the *cis* junction between rings *B*/*C* are in agreement with the structure reported previously.

Bispuupehenone was tested for the inhibitory activities against hPTP1B (human protein tyrosine phosphatase 1B), a key target for the treatment of Type-II diabetes and obesity, and showed excellent inhibitory effect with $IC_{50}$ value of 0.98 mg $ml^{-1}$. Other bioassays, such as antibacterial and anti-inflammatory, are currently ongoing.

### S2. Experimental

The specimens of sponge were collected from Lingshui Bay, Hainan Province, China, in July 2004, and identified as *Dysidea sp*. by Professor J.-H. Li of the Institute of Oceanology, Chinese Academy of Sciences. A voucher specimen (LS-210) is available for inspection at the Herbarium of Shanghai Institute of Materia Medica, CAS. The frozen animals (dry weight 96.3 g) were cut into small pieces and exhaustively extracted with acetone (3×3 *L*). The organic extract was evaporated to give a residue, which was partitioned between $Et_2O$ and $H_2O$. The $Et_2O$ solution was concentrated under reduced pressure to give a dark brown residue (4.7 g), which was fractionated by gradient silica gel column chromatography [0–100% acetone in light petroleum ether (PE)], yielding seven fractions (A···G). The fraction C eluted by PE/$Me_2CO$ (95:5) was further purified on a second silica gel column chromatography eluting with PE—$Et_2O$ (90:10) to afford (I) (14.3 mg). Crystals suitable for X-ray analysis were obtained by slow evaporation from a chloroform

solution.

### S3. Refinement

The non-H atoms were located in successive difference Fourier syntheses. The final refinements were performed by full-matrix least-squares methods with isotropic thermal parameters for all non-H atoms. Hydroxyl H atom H2 was found in a difference map and freely refined with an isotropic displacement parameter. Other H atoms were placed in calculated positions and included in the final refinement in the riding model approximation, with displacement parameters derived from the parent atoms to which they are bonded. In the absence of significant anomalous dispersion effects, 1571 measured Friedel pairs were merged and the absolute configuration was arbitrarily assigned.

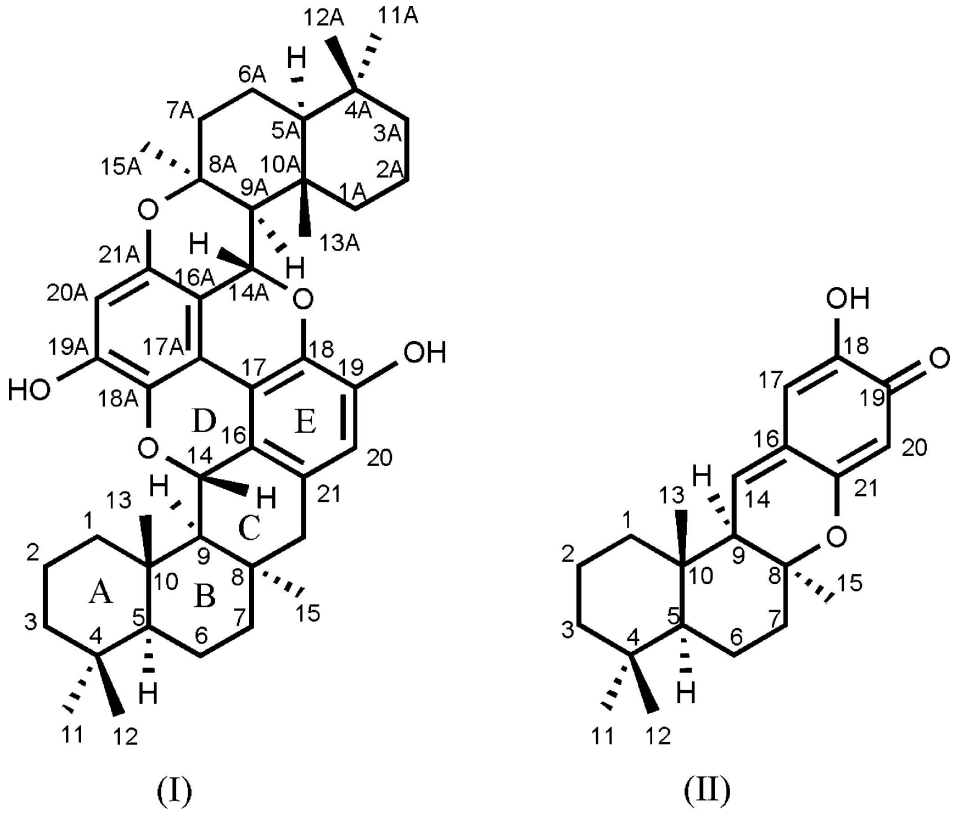


**Figure 1**

The structures of bispuupehenone (I) and puupehenone (II).

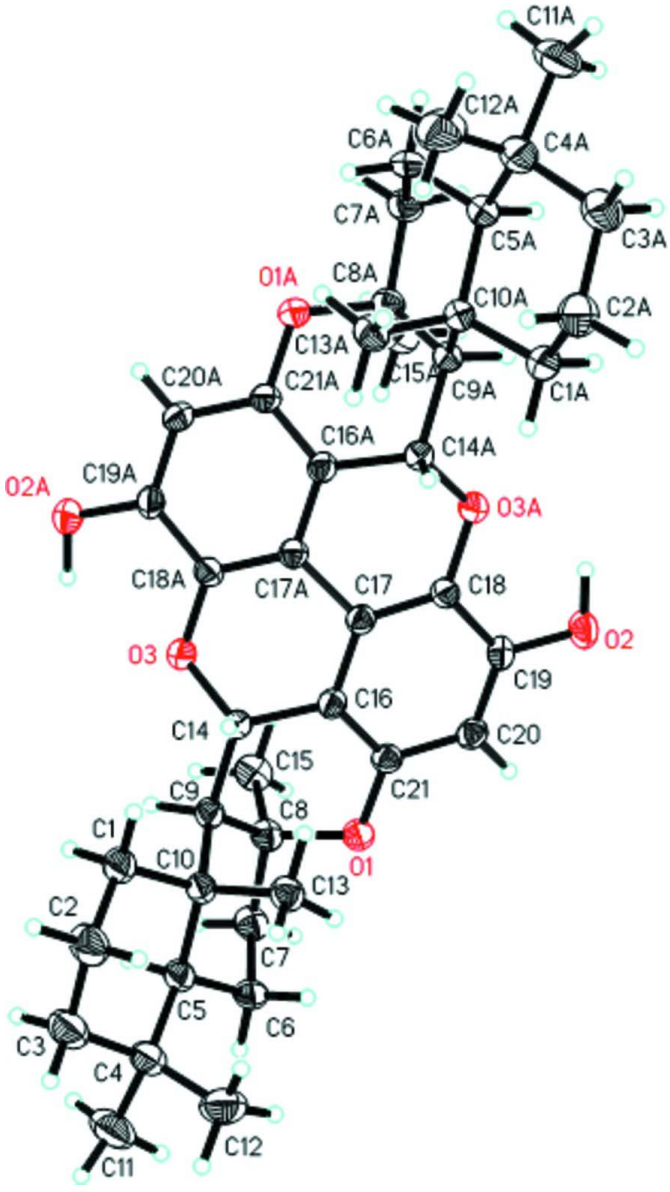


**Figure 2**

The projection of (I) showing the atom-labeling scheme.

**Bispuupehenone**

*Crystal data*

$C_{42}H_{54}O_6$
$M_r = 654.85$
Tetragonal, $P4_12_12$
Hall symbol: P 4abw 2nw
$a = 13.5981\ (10)$ Å
$c = 18.7260\ (19)$ Å
$V = 3462.6\ (5)$ Å$^3$
$Z = 4$
$F(000) = 1416$
$D_x = 1.256$ Mg m$^{-3}$
Mo $K\alpha$ radiation, $\lambda = 0.71073$ Å
Cell parameters from 4034 reflections
$\theta = 4.8–54.2°$
$\mu = 0.08$ mm$^{-1}$
$T = 293$ K
Prismatic, colourless
0.39 × 0.24 × 0.14 mm

*Data collection*

Bruker APEX CCD area-detector diffractometer
Radiation source: fine-focus sealed tube
Graphite monochromator
$\varphi$ and $\omega$ scans
Absorption correction: multi-scan (*SADABS*; Bruker, 2000)
$T_{min}$ = 0.743, $T_{max}$ = 0.990
20532 measured reflections
2219 independent reflections
1644 reflections with $I > 2\sigma(I)$
$R_{int}$ = 0.110
$\theta_{max}$ = 27.0°, $\theta_{min}$ = 1.9°
$h$ = −16→17
$k$ = −17→17
$l$ = −11→23

*Refinement*

Refinement on $F^2$
Least-squares matrix: full
$R[F^2 > 2\sigma(F^2)]$ = 0.045
$wR(F^2)$ = 0.113
$S$ = 0.95
2219 reflections
225 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 atoms treated by a mixture of independent and constrained refinement
$w = 1/[\sigma^2(F_o^2) + (0.07P)^2]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{max}$ = 0.007
$\Delta\rho_{max}$ = 0.23 e Å$^{-3}$
$\Delta\rho_{min}$ = −0.20 e Å$^{-3}$

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

| | *x* | *y* | *z* | $U_{iso}$*/$U_{eq}$ |
|---|---|---|---|---|
| O1 | 0.15743 (13) | 0.55657 (12) | 0.08619 (8) | 0.0429 (5) |
| O2 | 0.12262 (16) | 0.48461 (14) | 0.33312 (11) | 0.0530 (5) |
| O3 | 0.34879 (12) | 0.77308 (13) | 0.13171 (8) | 0.0415 (4) |
| C1 | 0.1684 (2) | 0.87117 (19) | −0.00763 (14) | 0.0499 (7) |
| H1A | 0.1694 | 0.9034 | 0.0386 | 0.060* |
| H1B | 0.2340 | 0.8757 | −0.0277 | 0.060* |
| C2 | 0.0968 (3) | 0.9254 (2) | −0.05633 (14) | 0.0637 (9) |
| H2A | 0.0322 | 0.9261 | −0.0345 | 0.076* |
| H2B | 0.1183 | 0.9930 | −0.0619 | 0.076* |
| C3 | 0.0904 (3) | 0.8771 (2) | −0.12908 (15) | 0.0681 (9) |
| H3A | 0.1538 | 0.8820 | −0.1525 | 0.082* |
| H3B | 0.0430 | 0.9126 | −0.1580 | 0.082* |
| C4 | 0.0601 (3) | 0.7683 (2) | −0.12559 (14) | 0.0573 (8) |
| C5 | 0.1302 (2) | 0.71542 (19) | −0.07258 (12) | 0.0431 (6) |
| H5 | 0.1954 | 0.7217 | −0.0944 | 0.052* |
| C6 | 0.1141 (2) | 0.6044 (2) | −0.06599 (13) | 0.0474 (7) |
| H6A | 0.0577 | 0.5915 | −0.0356 | 0.057* |
| H6B | 0.1010 | 0.5765 | −0.1127 | 0.057* |
| C7 | 0.2055 (2) | 0.5575 (2) | −0.03409 (13) | 0.0484 (7) |
| H7A | 0.1950 | 0.4871 | −0.0303 | 0.058* |
| H7B | 0.2604 | 0.5679 | −0.0664 | 0.058* |
| C8 | 0.2325 (2) | 0.59716 (19) | 0.03840 (13) | 0.0411 (6) |
| C9 | 0.23190 (19) | 0.71109 (17) | 0.04069 (12) | 0.0371 (6) |
| H9 | 0.2905 | 0.7323 | 0.0145 | 0.045* |

| | | | | |
|---|---|---|---|---|
| C10 | 0.14213 (18) | 0.76213 (18) | 0.00287 (13) | 0.0389 (6) |
| C11 | 0.0747 (3) | 0.7242 (3) | −0.20075 (15) | 0.0850 (12) |
| H11A | 0.0422 | 0.7649 | −0.2354 | 0.127* |
| H11B | 0.0472 | 0.6592 | −0.2022 | 0.127* |
| H11C | 0.1436 | 0.7211 | −0.2115 | 0.127* |
| C12 | −0.0502 (2) | 0.7571 (3) | −0.10853 (18) | 0.0746 (10) |
| H12A | −0.0662 | 0.7956 | −0.0672 | 0.112* |
| H12B | −0.0647 | 0.6892 | −0.0993 | 0.112* |
| H12C | −0.0884 | 0.7795 | −0.1485 | 0.112* |
| C13 | 0.0492 (2) | 0.7539 (2) | 0.04922 (13) | 0.0462 (6) |
| H13A | 0.0646 | 0.7722 | 0.0975 | 0.069* |
| H13B | 0.0257 | 0.6873 | 0.0483 | 0.069* |
| H13C | −0.0006 | 0.7969 | 0.0308 | 0.069* |
| C14 | 0.24566 (18) | 0.74743 (19) | 0.11748 (12) | 0.0365 (5) |
| H14 | 0.2065 | 0.8074 | 0.1231 | 0.044* |
| C15 | 0.3325 (2) | 0.5555 (2) | 0.06039 (15) | 0.0539 (7) |
| H15A | 0.3455 | 0.5721 | 0.1093 | 0.081* |
| H15B | 0.3829 | 0.5829 | 0.0305 | 0.081* |
| H15C | 0.3319 | 0.4852 | 0.0551 | 0.081* |
| C16 | 0.21009 (17) | 0.67425 (18) | 0.17229 (12) | 0.0355 (6) |
| C17 | 0.22961 (17) | 0.69613 (18) | 0.24324 (13) | 0.0351 (5) |
| C18 | 0.20089 (17) | 0.63566 (18) | 0.29797 (12) | 0.0359 (5) |
| C19 | 0.15135 (18) | 0.54863 (18) | 0.28072 (13) | 0.0384 (6) |
| C20 | 0.13528 (19) | 0.52376 (18) | 0.21062 (13) | 0.0401 (6) |
| H20 | 0.1029 | 0.4655 | 0.1997 | 0.048* |
| C21 | 0.16728 (18) | 0.58544 (18) | 0.15546 (13) | 0.0367 (6) |
| H2 | 0.149 (3) | 0.513 (3) | 0.3750 (19) | 0.086 (11)* |

*Atomic displacement parameters (Å²)*

| | $U^{11}$ | $U^{22}$ | $U^{33}$ | $U^{12}$ | $U^{13}$ | $U^{23}$ |
|---|---|---|---|---|---|---|
| O1 | 0.0538 (11) | 0.0380 (9) | 0.0370 (9) | −0.0081 (8) | 0.0003 (8) | −0.0055 (8) |
| O2 | 0.0695 (13) | 0.0420 (10) | 0.0474 (11) | −0.0153 (10) | 0.0097 (10) | 0.0052 (9) |
| O3 | 0.0395 (9) | 0.0490 (10) | 0.0360 (9) | −0.0103 (8) | 0.0026 (8) | −0.0008 (8) |
| C1 | 0.0642 (18) | 0.0418 (14) | 0.0436 (14) | −0.0107 (13) | −0.0004 (14) | 0.0011 (13) |
| C2 | 0.087 (2) | 0.0442 (16) | 0.0597 (19) | −0.0007 (17) | −0.0084 (18) | 0.0115 (14) |
| C3 | 0.092 (3) | 0.0619 (19) | 0.0507 (18) | −0.0038 (18) | −0.0139 (18) | 0.0132 (16) |
| C4 | 0.072 (2) | 0.0574 (18) | 0.0421 (15) | −0.0089 (15) | −0.0117 (15) | 0.0084 (15) |
| C5 | 0.0527 (15) | 0.0435 (14) | 0.0333 (13) | −0.0078 (13) | 0.0020 (12) | −0.0012 (11) |
| C6 | 0.0624 (18) | 0.0469 (15) | 0.0329 (13) | −0.0116 (14) | −0.0030 (13) | −0.0100 (12) |
| C7 | 0.0604 (18) | 0.0436 (15) | 0.0412 (14) | 0.0014 (13) | 0.0053 (14) | −0.0076 (12) |
| C8 | 0.0461 (15) | 0.0397 (13) | 0.0373 (13) | 0.0023 (12) | 0.0052 (12) | −0.0056 (12) |
| C9 | 0.0410 (13) | 0.0376 (12) | 0.0328 (13) | −0.0041 (11) | 0.0052 (11) | −0.0029 (11) |
| C10 | 0.0441 (14) | 0.0387 (13) | 0.0339 (12) | −0.0051 (11) | 0.0019 (11) | 0.0006 (11) |
| C11 | 0.134 (4) | 0.081 (2) | 0.0400 (18) | −0.012 (3) | −0.016 (2) | 0.0019 (17) |
| C12 | 0.071 (2) | 0.080 (2) | 0.073 (2) | −0.0043 (19) | −0.0276 (18) | 0.006 (2) |
| C13 | 0.0454 (15) | 0.0527 (16) | 0.0405 (14) | 0.0016 (14) | 0.0047 (12) | −0.0006 (13) |
| C14 | 0.0366 (12) | 0.0396 (13) | 0.0332 (13) | −0.0056 (11) | −0.0004 (10) | 0.0001 (11) |

| | | | | | | |
|---|---|---|---|---|---|---|
| C15 | 0.0551 (18) | 0.0540 (17) | 0.0526 (16) | 0.0122 (14) | 0.0044 (14) | −0.0041 (14) |
| C16 | 0.0325 (12) | 0.0365 (13) | 0.0375 (13) | −0.0026 (10) | 0.0022 (11) | −0.0009 (11) |
| C17 | 0.0318 (12) | 0.0374 (12) | 0.0360 (13) | −0.0021 (10) | 0.0019 (11) | −0.0025 (11) |
| C18 | 0.0353 (12) | 0.0404 (13) | 0.0321 (13) | −0.0011 (11) | 0.0022 (10) | −0.0017 (11) |
| C19 | 0.0402 (14) | 0.0343 (13) | 0.0407 (13) | −0.0035 (11) | 0.0071 (11) | 0.0036 (11) |
| C20 | 0.0432 (14) | 0.0341 (12) | 0.0430 (14) | −0.0062 (11) | 0.0003 (12) | −0.0051 (11) |
| C21 | 0.0380 (13) | 0.0375 (13) | 0.0345 (13) | −0.0014 (11) | 0.0002 (11) | −0.0047 (11) |

*Geometric parameters (Å, º)*

| | | | |
|---|---|---|---|
| O1—C21 | 1.362 (3) | C8—C9 | 1.550 (3) |
| O1—C8 | 1.465 (3) | C9—C14 | 1.532 (3) |
| O2—C19 | 1.369 (3) | C9—C10 | 1.573 (3) |
| O2—H2 | 0.95 (4) | C9—H9 | 0.9800 |
| O3—C18$^{i}$ | 1.380 (3) | C10—C13 | 1.537 (3) |
| O3—C14 | 1.469 (3) | C11—H11A | 0.9600 |
| C1—C2 | 1.524 (4) | C11—H11B | 0.9600 |
| C1—C10 | 1.538 (3) | C11—H11C | 0.9600 |
| C1—H1A | 0.9700 | C12—H12A | 0.9600 |
| C1—H1B | 0.9700 | C12—H12B | 0.9600 |
| C2—C3 | 1.515 (4) | C12—H12C | 0.9600 |
| C2—H2A | 0.9700 | C13—H13A | 0.9600 |
| C2—H2B | 0.9700 | C13—H13B | 0.9600 |
| C3—C4 | 1.536 (5) | C13—H13C | 0.9600 |
| C3—H3A | 0.9700 | C14—C16 | 1.509 (3) |
| C3—H3B | 0.9700 | C14—H14 | 0.9800 |
| C4—C12 | 1.541 (5) | C15—H15A | 0.9600 |
| C4—C11 | 1.543 (4) | C15—H15B | 0.9600 |
| C4—C5 | 1.553 (4) | C15—H15C | 0.9600 |
| C5—C6 | 1.530 (4) | C16—C21 | 1.377 (3) |
| C5—C10 | 1.558 (3) | C16—C17 | 1.387 (3) |
| C5—H5 | 0.9800 | C17—C18 | 1.371 (3) |
| C6—C7 | 1.520 (4) | C17—C17$^{i}$ | 1.450 (5) |
| C6—H6A | 0.9700 | C18—O3$^{i}$ | 1.380 (3) |
| C6—H6B | 0.9700 | C18—C19 | 1.399 (4) |
| C7—C8 | 1.506 (3) | C19—C20 | 1.373 (3) |
| C7—H7A | 0.9700 | C20—C21 | 1.400 (3) |
| C7—H7B | 0.9700 | C20—H20 | 0.9300 |
| C8—C15 | 1.530 (4) | | |
| | | | |
| C21—O1—C8 | 113.87 (18) | C10—C9—H9 | 106.0 |
| C19—O2—H2 | 103 (2) | C13—C10—C1 | 109.5 (2) |
| C18$^{i}$—O3—C14 | 112.36 (18) | C13—C10—C5 | 113.4 (2) |
| C2—C1—C10 | 113.2 (2) | C1—C10—C5 | 107.5 (2) |
| C2—C1—H1A | 108.9 | C13—C10—C9 | 110.58 (19) |
| C10—C1—H1A | 108.9 | C1—C10—C9 | 107.6 (2) |
| C2—C1—H1B | 108.9 | C5—C10—C9 | 108.0 (2) |
| C10—C1—H1B | 108.9 | C4—C11—H11A | 109.5 |

| | | | |
|---|---|---|---|
| H1A—C1—H1B | 107.7 | C4—C11—H11B | 109.5 |
| C3—C2—C1 | 111.4 (3) | H11A—C11—H11B | 109.5 |
| C3—C2—H2A | 109.3 | C4—C11—H11C | 109.5 |
| C1—C2—H2A | 109.3 | H11A—C11—H11C | 109.5 |
| C3—C2—H2B | 109.3 | H11B—C11—H11C | 109.5 |
| C1—C2—H2B | 109.3 | C4—C12—H12A | 109.5 |
| H2A—C2—H2B | 108.0 | C4—C12—H12B | 109.5 |
| C2—C3—C4 | 113.2 (3) | H12A—C12—H12B | 109.5 |
| C2—C3—H3A | 108.9 | C4—C12—H12C | 109.5 |
| C4—C3—H3A | 108.9 | H12A—C12—H12C | 109.5 |
| C2—C3—H3B | 108.9 | H12B—C12—H12C | 109.5 |
| C4—C3—H3B | 108.9 | C10—C13—H13A | 109.5 |
| H3A—C3—H3B | 107.7 | C10—C13—H13B | 109.5 |
| C3—C4—C12 | 111.4 (3) | H13A—C13—H13B | 109.5 |
| C3—C4—C11 | 107.5 (3) | C10—C13—H13C | 109.5 |
| C12—C4—C11 | 106.0 (3) | H13A—C13—H13C | 109.5 |
| C3—C4—C5 | 108.0 (2) | H13B—C13—H13C | 109.5 |
| C12—C4—C5 | 114.8 (2) | O3—C14—C16 | 109.82 (18) |
| C11—C4—C5 | 108.9 (3) | O3—C14—C9 | 111.31 (19) |
| C6—C5—C4 | 114.9 (2) | C16—C14—C9 | 112.7 (2) |
| C6—C5—C10 | 110.1 (2) | O3—C14—H14 | 107.6 |
| C4—C5—C10 | 117.1 (2) | C16—C14—H14 | 107.6 |
| C6—C5—H5 | 104.4 | C9—C14—H14 | 107.6 |
| C4—C5—H5 | 104.4 | C8—C15—H15A | 109.5 |
| C10—C5—H5 | 104.4 | C8—C15—H15B | 109.5 |
| C7—C6—C5 | 109.2 (2) | H15A—C15—H15B | 109.5 |
| C7—C6—H6A | 109.8 | C8—C15—H15C | 109.5 |
| C5—C6—H6A | 109.8 | H15A—C15—H15C | 109.5 |
| C7—C6—H6B | 109.8 | H15B—C15—H15C | 109.5 |
| C5—C6—H6B | 109.8 | C21—C16—C17 | 119.2 (2) |
| H6A—C6—H6B | 108.3 | C21—C16—C14 | 123.9 (2) |
| C8—C7—C6 | 113.7 (2) | C17—C16—C14 | 116.7 (2) |
| C8—C7—H7A | 108.8 | C18—C17—C16 | 122.2 (2) |
| C6—C7—H7A | 108.8 | C18—C17—C17$^{i}$ | 119.0 (3) |
| C8—C7—H7B | 108.8 | C16—C17—C17$^{i}$ | 116.7 (3) |
| C6—C7—H7B | 108.8 | C17—C18—O3$^{i}$ | 123.3 (2) |
| H7A—C7—H7B | 107.7 | C17—C18—C19 | 118.1 (2) |
| O1—C8—C7 | 104.3 (2) | O3$^{i}$—C18—C19 | 118.3 (2) |
| O1—C8—C15 | 108.4 (2) | O2—C19—C20 | 118.9 (2) |
| C7—C8—C15 | 109.0 (2) | O2—C19—C18 | 120.6 (2) |
| O1—C8—C9 | 110.86 (19) | C20—C19—C18 | 120.4 (2) |
| C7—C8—C9 | 112.5 (2) | C19—C20—C21 | 120.6 (2) |
| C15—C8—C9 | 111.6 (2) | C19—C20—H20 | 119.7 |
| C14—C9—C8 | 110.36 (19) | C21—C20—H20 | 119.7 |
| C14—C9—C10 | 112.0 (2) | O1—C21—C16 | 120.8 (2) |
| C8—C9—C10 | 115.6 (2) | O1—C21—C20 | 120.0 (2) |
| C14—C9—H9 | 106.0 | C16—C21—C20 | 119.2 (2) |
| C8—C9—H9 | 106.0 | | |

| | | | |
|---|---|---|---|
| C10—C1—C2—C3 | −57.4 (3) | C14—C9—C10—C1 | 67.9 (2) |
| C1—C2—C3—C4 | 57.2 (4) | C8—C9—C10—C1 | −164.5 (2) |
| C2—C3—C4—C12 | 74.3 (3) | C14—C9—C10—C5 | −176.30 (19) |
| C2—C3—C4—C11 | −169.9 (3) | C8—C9—C10—C5 | −48.7 (3) |
| C2—C3—C4—C5 | −52.6 (4) | C18$^{i}$—O3—C14—C16 | −50.0 (2) |
| C3—C4—C5—C6 | −176.6 (3) | C18$^{i}$—O3—C14—C9 | −175.53 (19) |
| C12—C4—C5—C6 | 58.5 (4) | C8—C9—C14—O3 | 97.3 (2) |
| C11—C4—C5—C6 | −60.1 (3) | C10—C9—C14—O3 | −132.3 (2) |
| C3—C4—C5—C10 | 52.0 (3) | C8—C9—C14—C16 | −26.6 (3) |
| C12—C4—C5—C10 | −73.0 (3) | C10—C9—C14—C16 | 103.8 (2) |
| C11—C4—C5—C10 | 168.4 (2) | O3—C14—C16—C21 | −126.5 (2) |
| C4—C5—C6—C7 | 160.9 (2) | C9—C14—C16—C21 | −1.7 (3) |
| C10—C5—C6—C7 | −64.4 (3) | O3—C14—C16—C17 | 48.3 (3) |
| C5—C6—C7—C8 | 58.8 (3) | C9—C14—C16—C17 | 173.0 (2) |
| C21—O1—C8—C7 | −178.8 (2) | C21—C16—C17—C18 | −5.2 (4) |
| C21—O1—C8—C15 | 65.2 (3) | C14—C16—C17—C18 | 179.8 (2) |
| C21—O1—C8—C9 | −57.6 (3) | C21—C16—C17—C17$^{i}$ | 158.50 (17) |
| C6—C7—C8—O1 | 72.2 (3) | C14—C16—C17—C17$^{i}$ | −16.5 (2) |
| C6—C7—C8—C15 | −172.2 (2) | C16—C17—C18—O3$^{i}$ | 174.0 (2) |
| C6—C7—C8—C9 | −47.9 (3) | C17$^{i}$—C17—C18—O3$^{i}$ | 10.7 (3) |
| O1—C8—C9—C14 | 55.9 (3) | C16—C17—C18—C19 | 0.8 (4) |
| C7—C8—C9—C14 | 172.2 (2) | C17$^{i}$—C17—C18—C19 | −162.49 (17) |
| C15—C8—C9—C14 | −64.9 (3) | C17—C18—C19—O2 | 178.8 (2) |
| O1—C8—C9—C10 | −72.5 (3) | O3$^{i}$—C18—C19—O2 | 5.2 (3) |
| C7—C8—C9—C10 | 43.8 (3) | C17—C18—C19—C20 | 2.1 (4) |
| C15—C8—C9—C10 | 166.6 (2) | O3$^{i}$—C18—C19—C20 | −171.5 (2) |
| C2—C1—C10—C13 | −70.9 (3) | O2—C19—C20—C21 | −177.3 (2) |
| C2—C1—C10—C5 | 52.7 (3) | C18—C19—C20—C21 | −0.6 (4) |
| C2—C1—C10—C9 | 168.9 (2) | C8—O1—C21—C16 | 28.2 (3) |
| C6—C5—C10—C13 | −64.4 (3) | C8—O1—C21—C20 | −150.7 (2) |
| C4—C5—C10—C13 | 69.2 (3) | C17—C16—C21—O1 | −172.3 (2) |
| C6—C5—C10—C1 | 174.4 (2) | C14—C16—C21—O1 | 2.3 (4) |
| C4—C5—C10—C1 | −52.0 (3) | C17—C16—C21—C20 | 6.5 (4) |
| C6—C5—C10—C9 | 58.5 (3) | C14—C16—C21—C20 | −178.9 (2) |
| C4—C5—C10—C9 | −167.9 (2) | C19—C20—C21—O1 | 175.1 (2) |
| C14—C9—C10—C13 | −51.7 (3) | C19—C20—C21—C16 | −3.7 (4) |
| C8—C9—C10—C13 | 75.9 (3) | | |

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

*Hydrogen-bond geometry (Å, º)*

| *D*—H···*A* | *D*—H | H···*A* | *D*···*A* | *D*—H···*A* |
|---|---|---|---|---|
| O2—H2···O3$^{i}$ | 0.95 (4) | 2.16 (4) | 2.753 (3) | 120 (3) |

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