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Key indicators

Single-crystal X-ray study
T = 120 K
Mean $\sigma(\text{C}-\text{C}) = 0.002 \text{ \AA}$
R factor = 0.041
wR factor = 0.115
Data-to-parameter ratio = 17.0

For details of how these key indicators were automatically derived from the article, see <http://journals.iucr.org/e>.

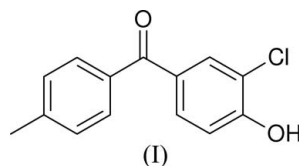
3-Chloro-4-hydroxy-4'-methylbenzophenone

The title compound, $\text{C}_{14}\text{H}_{11}\text{ClO}_2$, possesses normal geometrical parameters. The two benzene rings are twisted by $54.70(4)^\circ$, perhaps as a result of steric repulsion between H atoms. The crystal packing is consolidated by an $\text{O}-\text{H}\cdots\text{O}$ hydrogen bond, $\pi-\pi$ stacking and $\text{C}-\text{H}\cdots\text{O}$ and $\text{C}-\text{H}\cdots\pi$ interactions, resulting in a two-dimensional network.

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Comment

The title compound, (I) (Fig. 1), is an intermediate for the synthesis of podophyllotoxin and its derivatives which have pharmaceutical applications (Basavaraju & Devaraju, 2002). More generally, benzophenone derivatives have many applications in organic chemistry (Sieron *et al.*, 2004; Khanum *et al.*, 2005).



Compound (I) possesses normal geometrical parameters (Allen *et al.*, 1995). The dihedral angle, δ , between the mean planes of the two benzene rings (atoms C1–C6 and C8–C13) is $54.70(4)^\circ$. The C–C_c (c = carbonyl) C6–C7 [1.480(2) Å] and C7–C8 [1.482(2) Å] bond lengths are only slightly shorter than normal C–C single bonds, indicating negligible conjugation between the two aromatic ring systems. The rings may be twisted as a result of steric repulsion between the C5 and C9 H atoms ($\text{H5}\cdots\text{H9} = 2.40 \text{ \AA}$; van der Waals contact distance = 2.40 \AA), although we note that H9 also participates in a $\text{C}-\text{H}\cdots\text{O}$ interaction (see below). Many other substituted benzophenones possess similar geometrical parameters for the equivalent distances and angles. For example, in 4-dimethylamino-4'-[bis(2-hydroxyethyl)amino]benzophenone

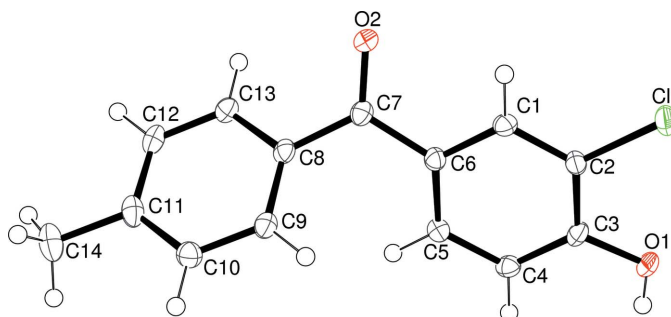


Figure 1
The molecular structure of (I), with 50% probability displacement ellipsoids (arbitrary spheres for the H atoms).

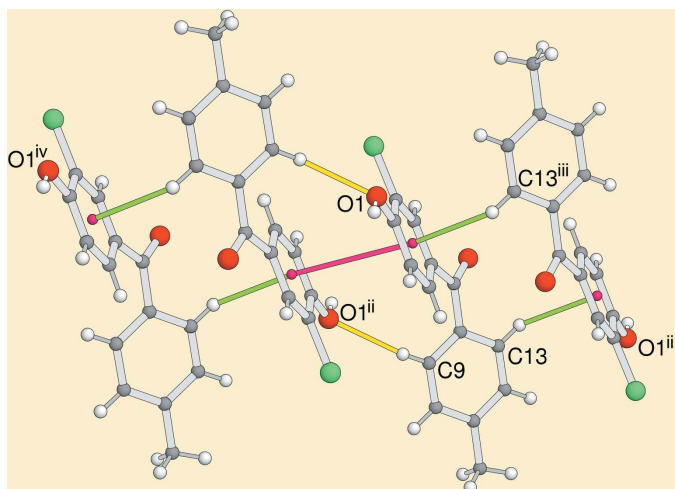


Figure 2
Detail of (I) showing how π - π stacking (pink line) and C-H...O (yellow lines) and C-H... π (green lines) weak intermolecular interactions help to establish the crystal packing. Symmetry codes as in Table 1; additionally (iv) $1 - x, 1 - y, -z$.

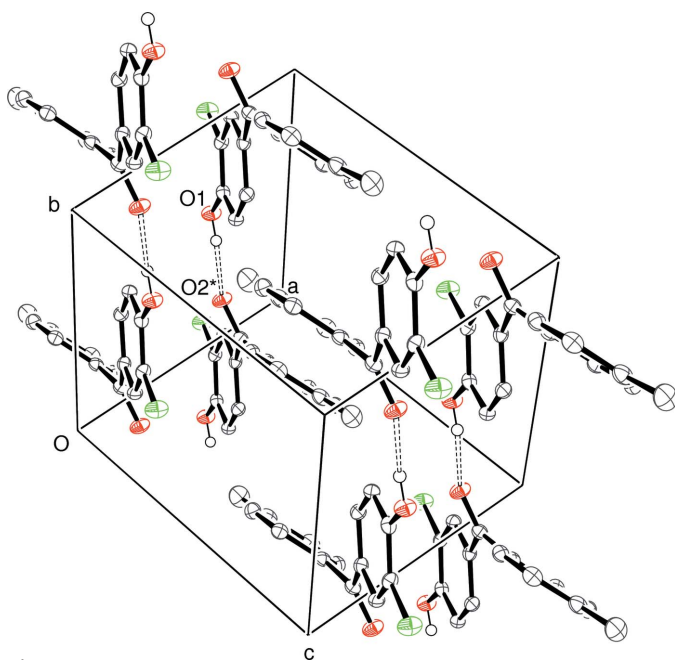


Figure 3
The packing for (I), with all H atoms except H1 omitted for clarity. The O-H...O hydrogen bond is indicated by a dashed line. The molecule containing O2* is generated by the symmetry code $(x, 1 + y, z)$.

(El Sayed *et al.*, 2001), H...H = 2.38 Å, C-C_c = 1.460 (3) and 1.484 (3) Å, and $\delta = 47.4 (1)^\circ$, and in (3-chlorophenyl)(2-hydroxy-5-methylphenyl)methanone (Khanum *et al.*, 2005) H...H = 2.52 Å, C-C_c = 1.468 (3) and 1.493 (3) Å, and $\delta = 57.37 (12)^\circ$.

As well as van der Waals forces, the crystal packing in (I) appears to be controlled by several different intermolecular interactions (Table 1). The most clearcut is an O-H...O hydrogen bond that links adjacent molecules of (I) in the *b*-axis direction. Fig. 2 shows that π - π stacking occurs between adjacent inversion-related C1-C6 benzene rings, with a

centroid-centroid separation of 3.7642 (10) Å and an interplanar distance of 3.357 Å. Additionally, a *PLATON* (Spek, 2003) analysis of (I) identified probable C-H...O and C-H... π interactions (Table 1). Together, these interactions lead to a two-dimensional network that propagates in the *ab* plane. The packing is shown in Fig. 3.

Experimental

A solution of *o*-chlorophenol (1 g, 0.0077 mol) in dry dichloromethane (10 ml) was treated with anhydrous aluminium chloride (1.037 g, 0.0077 mol). The reaction mixture was stirred continuously for 30 min and then cooled. To this, a solution of toluoyl chloride (1.203 g, 0.0077 mol) in methylene chloride (10 ml) was added dropwise and the mixture kept overnight. After 24 h, about 5 ml of concentrated HCl was added and the reaction mixture was stirred for another 24 h. Aqueous NaCl solution (10%) was added to break the emulsion and the lower organic layer was separated and washed with 10% brine. Excess dichloromethane was distilled off on a water bath. The concentrated solution was kept overnight, resulting in a pale-brown solid (yield: 89.2%; m.p. 352 K). Colourless single crystals of (I) were recrystallized from a 1:1 mixture of acetone and acetonitrile.

Crystal data

C₁₄H₁₁ClO₂
M_r = 246.68
 Triclinic, *P* $\bar{1}$
a = 7.1062 (3) Å
b = 8.5441 (5) Å
c = 9.8766 (6) Å
 α = 86.124 (3)°
 β = 83.804 (3)°
 γ = 77.290 (3)°
V = 580.96 (5) Å³

Z = 2
D_x = 1.410 Mg m⁻³
 Mo *K* α radiation
 Cell parameters from 2534 reflections
 θ = 2.9–27.5°
 μ = 0.31 mm⁻¹
T = 120 (2) K
 Cut block, colourless
 0.32 × 0.16 × 0.10 mm

Data collection

Nonius KappaCCD diffractometer
 ω scans
 Absorption correction: multi-scan (SADABS; Bruker, 2003)
T_{min} = 0.906, *T_{max}* = 0.969
 11199 measured reflections
 2684 independent reflections

2037 reflections with *I* > 2 σ (*I*)
R_{int} = 0.048
 θ_{\max} = 27.8°
h = -9 → 9
k = -11 → 11
l = -12 → 12

Refinement

Refinement on *F*²
R [*F*² > 2 σ (*F*²)] = 0.041
wR (*F*²) = 0.115
S = 1.05
 2684 reflections
 158 parameters

H atoms treated by a mixture of independent and constrained refinement
 $w = 1/[\sigma^2(F_o^2) + (0.0595P)^2 + 0.1677P]$
 where $P = (F_o^2 + 2F_c^2)/3$
 $(\Delta/\sigma)_{\max} < 0.001$
 $\Delta\rho_{\max} = 0.25 \text{ e \AA}^{-3}$
 $\Delta\rho_{\min} = -0.35 \text{ e \AA}^{-3}$

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

<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>
O1-H1...O2 ⁱ	0.78 (2)	1.93 (2)	2.6418 (17)	150 (2)
C9-H9...O1 ⁱⁱ	0.95	2.48	3.375 (2)	157
C13-H13...Cg1 ⁱⁱⁱ	0.95	2.59	3.3908 (17)	142

Symmetry codes: (i) $x, y - 1, z$; (ii) $-x + 2, -y + 1, -z$; (iii) $-x + 1, -y + 2, -z$. Cg1 is the centroid of the C1-C6 ring

The hydroxy H atom was located in a difference map and its position was freely refined with the constraint $U_{\text{iso}}(\text{H}) = 1.2U_{\text{eq}}(\text{O})$. Other H atoms were placed in calculated positions ($\text{C}-\text{H} = 0.95\text{--}0.98 \text{ \AA}$) and refined as riding, with $U_{\text{iso}}(\text{H}) = 1.2U_{\text{eq}}(\text{carrier})$ or $1.5U_{\text{eq}}(\text{methyl carrier})$. The $-\text{CH}_3$ group was rotated to fit the electron density.

Data collection: *COLLECT* (Nonius, 1998); cell refinement: *SCALEPACK* (Otwinowski & Minor, 1997); data reduction: *SCALEPACK* and *DENZO* (Otwinowski & Minor, 1997) and *SORTAV* (Blessing, 1995); program(s) used to solve structure: *SHELXS97* (Sheldrick, 1997); program(s) used to refine structure: *SHELXL97* (Sheldrick, 1997); molecular graphics: *ORTEP3* (Farrugia, 1997); software used to prepare material for publication: *SHELXL97*.

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References

- Allen, F. H., Kennard, O., Watson, D. G., Brammer, L., Orpen, A. G. & Taylor, R. (1995). *International Tables for Crystallography*, Vol. C, Section 9.5, pp. 685–706. Dordrecht: Kluwer Academic Publishers.
- Basavaraju, Y. B. & Devaraju (2002). *Indian J. Heterocycl. Chem.* **11**, 229–232.
- Blessing, R. H. (1995). *Acta Cryst.* **A51**, 33–38.
- Bruker (2003). *SADABS*. Bruker AXS Inc., Madison, Wisconsin, USA.
- El Sayed, M., Müller, H., Rheinwald, G., Lang, H. & Spange, S. (2001). *J. Phys. Org. Chem.* **14**, 247–255.
- Farrugia, L. J. (1997). *J. Appl. Cryst.* **30**, 565.
- Khanum, S. A., Mahendra, M., Shashikantha, S., Doreswarmy, B. H., Sridhar, M. A. & Shashidara Prasad, J. (2005). *Acta Cryst.* **E61**, o3615–o3617.
- Nonius (1998). *COLLECT*. Nonius BV, Delft, The Netherlands.
- Otwinowski, Z. & Minor, W. (1997). *Methods in Enzymology*, Vol. 276, *Macromolecular Crystallography, Part A*, edited by C. W. Carter Jr & R. M. Sweet, pp. 307–326. New York: Academic Press.
- Sheldrick, G. M. (1997). *SHELXS97* and *SHELXL97*. University of Göttingen, Germany.
- Sieron, L., Shashikanth, S., Yathirajan, H. S., Venu, T. D., Nagaraj, B., Nagaraja, P. & Khanum, S. A. (2004). *Acta Cryst.* **E60**, o1889–o1891.
- Spek, A. L. (2003). *J. Appl. Cryst.* **36**, 7–13.

supporting information

Acta Cryst. (2005). E61, o4146–o4148 [https://doi.org/10.1107/S1600536805036780]

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$V = 580.96$ (5) Å³

$Z = 2$

$F(000) = 256$

$D_x = 1.410$ Mg m⁻³

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$\theta = 2.9$ – 27.5 °

$\mu = 0.31$ mm⁻¹

$T = 120$ K

Cut block, colourless

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diffractometer

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Graphite monochromator

ω scans

Absorption correction: multi-scan

(SADABS; Bruker, 2003)

$T_{\min} = 0.906$, $T_{\max} = 0.969$

11199 measured reflections

2684 independent reflections

2037 reflections with $I > 2\sigma(I)$

$R_{\text{int}} = 0.048$

$\theta_{\max} = 27.8$ °, $\theta_{\min} = 3.3$ °

$h = -9 \rightarrow 9$

$k = -11 \rightarrow 11$

$l = -12 \rightarrow 12$

Refinement

Refinement on F^2

Least-squares matrix: full

$R[F^2 > 2\sigma(F^2)] = 0.041$

$wR(F^2) = 0.115$

$S = 1.05$

2684 reflections

158 parameters

0 restraints

Primary atom site location: structure-invariant

direct methods

Secondary atom site location: difference Fourier map

Hydrogen site location: difmap (O-H) and geom (others)

H atoms treated by a mixture of independent and constrained refinement

$w = 1/[\sigma^2(F_o^2) + (0.0595P)^2 + 0.1677P]$

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

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

$\Delta\rho_{\max} = 0.25$ e Å⁻³

$\Delta\rho_{\min} = -0.35$ e Å⁻³

Special details

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 (\AA^2)

	<i>x</i>	<i>y</i>	<i>z</i>	$U_{\text{iso}}^*/U_{\text{eq}}$
C1	0.8691 (2)	0.7775 (2)	-0.13871 (18)	0.0173 (4)
H2	0.9198	0.8558	-0.1953	0.021*
C2	0.8806 (2)	0.6279 (2)	-0.18629 (17)	0.0169 (4)
C3	0.8048 (2)	0.5108 (2)	-0.10592 (18)	0.0171 (4)
C4	0.7215 (2)	0.5473 (2)	0.02553 (18)	0.0179 (4)
H4	0.6712	0.4686	0.0820	0.021*
C5	0.7113 (2)	0.6977 (2)	0.07467 (18)	0.0176 (4)
H5	0.6550	0.7208	0.1647	0.021*
C6	0.7830 (2)	0.8149 (2)	-0.00730 (17)	0.0164 (4)
C7	0.7567 (2)	0.9819 (2)	0.03481 (18)	0.0175 (4)
C8	0.7257 (2)	1.0217 (2)	0.18041 (18)	0.0171 (4)
C9	0.8176 (3)	0.9232 (2)	0.28295 (18)	0.0188 (4)
H9	0.8970	0.8213	0.2621	0.023*
C10	0.7929 (3)	0.9743 (2)	0.41554 (19)	0.0213 (4)
H10	0.8573	0.9070	0.4845	0.026*
C11	0.6753 (3)	1.1224 (2)	0.44931 (19)	0.0225 (4)
C12	0.5813 (3)	1.2185 (2)	0.34659 (19)	0.0219 (4)
H12	0.4984	1.3189	0.3680	0.026*
C13	0.6067 (2)	1.1701 (2)	0.21448 (18)	0.0186 (4)
H13	0.5428	1.2382	0.1457	0.022*
C14	0.6528 (3)	1.1784 (3)	0.5928 (2)	0.0324 (5)
H14A	0.5353	1.2631	0.6058	0.049*
H14B	0.7659	1.2207	0.6083	0.049*
H14C	0.6426	1.0879	0.6576	0.049*
O1	0.81397 (19)	0.36984 (15)	-0.16234 (13)	0.0220 (3)
H1	0.780 (3)	0.308 (3)	-0.108 (2)	0.026*
O2	0.75791 (19)	1.09033 (14)	-0.05454 (13)	0.0235 (3)
Cl1	0.99046 (7)	0.58148 (5)	-0.34839 (5)	0.02638 (17)

Atomic displacement parameters (\AA^2)

	U^{11}	U^{22}	U^{33}	U^{12}	U^{13}	U^{23}
C1	0.0197 (9)	0.0155 (8)	0.0175 (9)	-0.0062 (7)	-0.0020 (7)	0.0008 (7)
C2	0.0189 (9)	0.0175 (9)	0.0138 (9)	-0.0020 (7)	-0.0013 (7)	-0.0027 (7)
C3	0.0182 (8)	0.0122 (8)	0.0215 (9)	-0.0023 (7)	-0.0055 (7)	-0.0035 (7)
C4	0.0195 (9)	0.0163 (9)	0.0191 (9)	-0.0066 (7)	-0.0029 (7)	0.0017 (7)

C5	0.0188 (9)	0.0182 (9)	0.0157 (9)	-0.0037 (7)	-0.0015 (7)	-0.0012 (7)
C6	0.0176 (9)	0.0162 (8)	0.0156 (9)	-0.0029 (7)	-0.0034 (7)	-0.0020 (7)
C7	0.0174 (9)	0.0164 (9)	0.0196 (9)	-0.0051 (7)	-0.0010 (7)	-0.0025 (7)
C8	0.0188 (8)	0.0157 (8)	0.0188 (9)	-0.0078 (7)	-0.0015 (7)	-0.0027 (7)
C9	0.0202 (9)	0.0167 (9)	0.0203 (9)	-0.0053 (7)	-0.0008 (7)	-0.0033 (7)
C10	0.0236 (9)	0.0219 (9)	0.0203 (10)	-0.0077 (8)	-0.0047 (7)	-0.0002 (7)
C11	0.0224 (9)	0.0277 (10)	0.0203 (10)	-0.0114 (8)	0.0019 (7)	-0.0082 (8)
C12	0.0221 (9)	0.0171 (9)	0.0266 (10)	-0.0040 (8)	0.0006 (8)	-0.0079 (8)
C13	0.0189 (9)	0.0160 (8)	0.0217 (10)	-0.0045 (7)	-0.0029 (7)	-0.0023 (7)
C14	0.0344 (11)	0.0406 (12)	0.0239 (11)	-0.0101 (10)	0.0013 (9)	-0.0137 (9)
O1	0.0331 (8)	0.0122 (6)	0.0218 (7)	-0.0071 (6)	-0.0003 (6)	-0.0035 (5)
O2	0.0368 (8)	0.0146 (6)	0.0192 (7)	-0.0063 (6)	-0.0012 (6)	0.0000 (5)
Cl1	0.0371 (3)	0.0229 (3)	0.0189 (3)	-0.0084 (2)	0.00578 (19)	-0.00673 (18)

Geometric parameters (Å, °)

C1—C2	1.374 (2)	C8—C13	1.400 (2)
C1—C6	1.400 (2)	C9—C10	1.389 (3)
C1—H2	0.9500	C9—H9	0.9500
C2—C3	1.400 (2)	C10—C11	1.393 (3)
C2—Cl1	1.7349 (17)	C10—H10	0.9500
C3—O1	1.346 (2)	C11—C12	1.394 (3)
C3—C4	1.393 (2)	C11—C14	1.507 (3)
C4—C5	1.388 (2)	C12—C13	1.377 (3)
C4—H4	0.9500	C12—H12	0.9500
C5—C6	1.395 (2)	C13—H13	0.9500
C5—H5	0.9500	C14—H14A	0.9800
C6—C7	1.480 (2)	C14—H14B	0.9800
C7—O2	1.236 (2)	C14—H14C	0.9800
C7—C8	1.482 (2)	O1—H1	0.78 (2)
C8—C9	1.395 (2)		
C2—C1—C6	120.31 (16)	C13—C8—C7	117.82 (15)
C2—C1—H2	119.8	C10—C9—C8	119.97 (17)
C6—C1—H2	119.8	C10—C9—H9	120.0
C1—C2—C3	121.09 (16)	C8—C9—H9	120.0
C1—C2—Cl1	120.04 (14)	C9—C10—C11	121.24 (17)
C3—C2—Cl1	118.87 (13)	C9—C10—H10	119.4
O1—C3—C4	124.00 (16)	C11—C10—H10	119.4
O1—C3—C2	117.39 (16)	C10—C11—C12	118.31 (17)
C4—C3—C2	118.60 (15)	C10—C11—C14	120.88 (18)
C5—C4—C3	120.55 (16)	C12—C11—C14	120.80 (17)
C5—C4—H4	119.7	C13—C12—C11	120.97 (17)
C3—C4—H4	119.7	C13—C12—H12	119.5
C4—C5—C6	120.45 (16)	C11—C12—H12	119.5
C4—C5—H5	119.8	C12—C13—C8	120.71 (17)
C6—C5—H5	119.8	C12—C13—H13	119.6
C5—C6—C1	118.97 (15)	C8—C13—H13	119.6

C5—C6—C7	122.40 (16)	C11—C14—H14A	109.5
C1—C6—C7	118.42 (15)	C11—C14—H14B	109.5
O2—C7—C6	118.64 (15)	H14A—C14—H14B	109.5
O2—C7—C8	119.70 (15)	C11—C14—H14C	109.5
C6—C7—C8	121.65 (15)	H14A—C14—H14C	109.5
C9—C8—C13	118.79 (16)	H14B—C14—H14C	109.5
C9—C8—C7	123.28 (16)	C3—O1—H1	110.8 (17)
C6—C1—C2—C3	0.8 (3)	C1—C6—C7—C8	-160.64 (15)
C6—C1—C2—C11	-179.11 (12)	O2—C7—C8—C9	-144.16 (17)
C1—C2—C3—O1	177.04 (16)	C6—C7—C8—C9	37.0 (2)
C11—C2—C3—O1	-3.0 (2)	O2—C7—C8—C13	32.0 (2)
C1—C2—C3—C4	-1.7 (3)	C6—C7—C8—C13	-146.81 (16)
C11—C2—C3—C4	178.26 (13)	C13—C8—C9—C10	-1.1 (2)
O1—C3—C4—C5	-177.62 (16)	C7—C8—C9—C10	175.03 (16)
C2—C3—C4—C5	1.0 (3)	C8—C9—C10—C11	0.8 (3)
C3—C4—C5—C6	0.5 (3)	C9—C10—C11—C12	0.4 (3)
C4—C5—C6—C1	-1.4 (3)	C9—C10—C11—C14	-178.65 (17)
C4—C5—C6—C7	173.28 (16)	C10—C11—C12—C13	-1.3 (3)
C2—C1—C6—C5	0.7 (3)	C14—C11—C12—C13	177.77 (17)
C2—C1—C6—C7	-174.16 (15)	C11—C12—C13—C8	1.0 (3)
C5—C6—C7—O2	-154.18 (17)	C9—C8—C13—C12	0.3 (3)
C1—C6—C7—O2	20.5 (2)	C7—C8—C13—C12	-176.10 (15)
C5—C6—C7—C8	24.7 (3)		

Hydrogen-bond geometry (\AA , $^\circ$)

<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>
O1—H1 \cdots O2 ⁱ	0.78 (2)	1.93 (2)	2.6418 (17)	150 (2)
C9—H9 \cdots O1 ⁱⁱ	0.95	2.48	3.375 (2)	157
C13—H13 \cdots Cg1 ⁱⁱⁱ	0.95	2.59	3.3908 (17)	142

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