Acta Crystallographica Section C
Crystal Structure Communications
ISSN 0108-2701

Hydrogen-bonded assemblages in 2,6-bis(hydroxymethyl)-4-*R*-phenol, with *R* = methyl, methoxy, phenoxy and 1-(4-methoxyphenyl)-1-methylethyl

Bernardo Masci[a] and Pierre Thuéry[b]*

[a]Dipartimento di Chimica, Università 'La Sapienza', Box 34, Roma 62, P.le Aldo Moro 5, 00185 Roma, Italy, and [b]CEA/Saclay, DSM/DRECAM/SCM (CNRS URA 331), Bâtiment 125, 91191 Gif-sur-Yvette, France
Correspondence e-mail: thuery@drecam.cea.fr

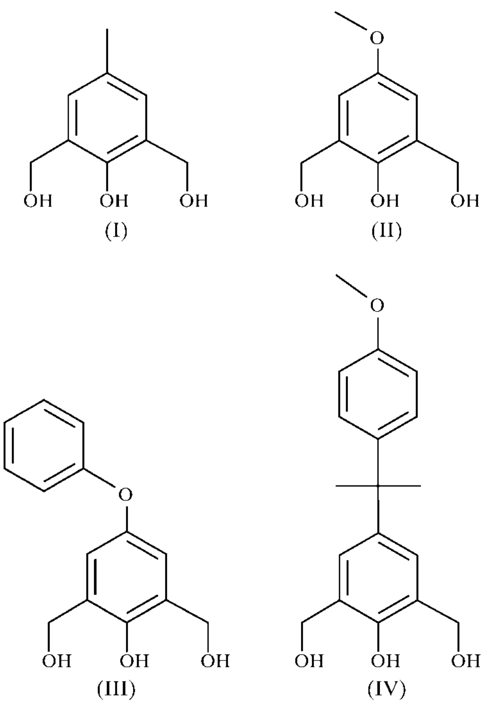
Received 13 June 2002
Accepted 22 July 2002
Online 31 August 2002

Four derivatives of 2,6-bis(hydroxymethyl)phenol, with various *para* substituents, have been investigated; these are 2,6-bis(hydroxymethyl)-4-methylphenol, $C_9H_{12}O_3$, (I), 2,6-bis(hydroxymethyl)-4-methoxyphenol, $C_9H_{12}O_4$, (II), 2,6-bis(hydroxymethyl)-4-phenoxyphenol, $C_{14}H_{14}O_4$, (III), and 2,6-bis(hydroxymethyl)-4-[1-(4-methoxyphenyl)-1-methylethyl]phenol, $C_{18}H_{22}O_4$, (IV). All four structures display hydrogen-bonding networks resulting in sheets, with possible weak intersheet π–π interactions in one case. In all the structures but one, the molecules form centrosymmetric dimeric subunits held together by two hydrogen bonds between the hydroxymethyl groups and, in two cases, by probable π–π interactions.

Comment

Para derivatives of 2,6-bis(hydroxymethyl)phenol are intermediates in the synthesis of calixarenes (Gutsche, 1989) and homooxacalixarenes (Masci, 2001). A search of the Cambridge Structural Database (Version 5.22; Allen & Kennard, 1993) gives few structural determinations of such compounds, those reported being for 2,6-bis(hydroxymethyl)-4-isopropylphenol (Oehler *et al.*, 1985), 2,6-bis(hydroxymethyl)-4-phenylphenol (Perrin & Cherared, 1986), 2,4,6-tris(hydroxymethyl)phenol and 3,5,3′,5′-tetrahydroxymethyl-4,4′-dihydroxydiphenylmethane (Perrin *et al.*, 1986), and 4-bromo-2,6-bis(hydroxymethyl)phenol (Crisp *et al.*, 2000). These compounds have been shown to crystallize as extensively hydrogen-bonded two- or three-dimensional assemblages. We report herein the crystal structures of four new compounds in this series, *viz*. (I)–(IV) in the *Scheme* below.

The molecule of (I), with a 4-methyl substituent, can be viewed as part of the 4-methylhexahomotrioxacalix[3]arene structure (Masci, 2001). The O atom of one of the hydroxymethyl groups (O1; Fig. 1) is close to the mean plane of the aromatic ring, at a distance of 0.106 (3) Å. The second hydroxymethyl O atom (O3) is more strongly displaced, by 1.386 (3) Å, on the same side of this plane. The three OH groups of the molecule are involved in hydrogen bonds, as both donors and acceptors, which results in six hydrogen bonds linking each molecule to four neighbours (Table 1). Sheets are formed parallel to the *bc* plane, most likely held together by van der Waals interactions (Fig. 2). The molecules, with phenol groups alternately up and down, have their aromatic rings roughly perpendicular to the sheets. Inside the sheets, the molecules are tightly associated in dimeric subunits around symmetry centres, by two hydrogen bonds between complementary hydroxymethyl groups and by probable π–π interactions between the parallel aromatic rings [distance between the centroids = 3.835 (3) Å, interplanar spacing = 3.481 (3) Å and centroid offset = 1.609 (3) Å; rings related by the inversion centre at $(\frac{1}{2},0,\frac{1}{2})$]. The shortest interatomic contact [$C2\cdots C6^{i}$ 3.479 (3) Å; symmetry code: (i) $1-x$, $-y$, $1-z$] is only slightly longer than twice the van der Waals radius of carbon (1.7 Å), which, together with the other geometric parameters, is indicative of π–π interactions. Such dimers were also present in 2,6-bis(hydroxymethyl)-4-isopropylphenol, 2,4,6-trihydroxymethylphenol (with four hydrogen bonds) and 4-bromo-2,6-bis(hydroxymethyl)phenol. As in some previous cases, no intramolecular hydrogen bonding is present, which has been considered an indication that such bonds cannot be invoked to explain the stability of these compounds (Perrin *et al.*, 1986).



With a 4-methoxy substituent in place of the methyl group, compound (II) presents additional possibilities for hydrogen-bonding interactions. As in (I), one of the hydroxymethyl O atoms (O3; Fig. 3) is located near the aromatic mean plane, at a distance of 0.153 (3) Å, whereas the other hydroxymethyl O atom (O1) is more displaced [0.966 (3) Å] and is on the other

DOI: 10.1107/S0108270102013239

side of the plane. The C atom of the methoxy substituent is close to the plane [0.107 (4) Å], on the same side as atom O1. Each molecule is involved in six hydrogen bonds with four neighbours, the phenolic atom O2 being a donor only, whereas atoms O1 and O3 are both donors and acceptors (Table 2). Sheets are formed parallel to the *bc* plane, as in (I), but there is no dimerization in this case and the molecules are not perpendicular to the sheet plane (Fig. 4).

The situation is somewhat different in compound (III), which differs from (II) by the presence of a phenoxy group in place of the methoxy substituent. Atom O3 is close to the mean aromatic plane [0.272 (6) Å], whereas atoms O1 and C9 are more distant, at distances of 1.110 (6) and 1.184 (6) Å, respectively; atom O1 is on the same side as O3, and atom C9 is on the other side (Fig. 5). Six hydrogen bonds link each molecule to four of its neighbours, atoms O1, O2 and O3 being donors as well as acceptors (Table 3). Atom O4 is not involved in hydrogen bonding, probably due to the bulkiness of the benzene-ring substituent. As in (I), centrosymmetric dimers are formed, which are held together by two complementary hydrogen bonds between hydroxymethyl groups and probable π–π interactions [distance between the centroids = 3.953 (3) Å, interplanar spacing = 3.602 (3) Å and centroid offset = 1.629 (3) Å; rings related by the inversion centre at $(0,1,\frac{1}{2})$]. This interaction is weaker than in compound (I), as indicated also by the shortest interatomic contact between the two rings [$\mathrm{C2}\cdots\mathrm{C4}^{\mathrm{ii}}$ 3.683 (3) Å; symmetry code: (ii) $-x$, $2-y$, $1-z$]. Sheets are formed parallel to the *bc* plane, but the phenol aromatic rings are nearly parallel to this plane, whereas the benzene rings, which are roughly perpendicular to the former [dihedral angle of 81.9 (1)°], project on either side of the plane (Fig. 6). The sheets can thus be viewed as hydrophilic at the centre and hydrophobic at the borders. In addition to van der Waals interactions, some weak π–π interactions are possibly involved to ensure cohesion between the sheets [distance between the centroids = 4.208 (3) Å,

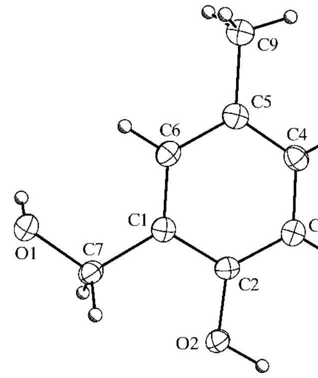


Figure 1
View of the molecule of (I), showing the atom-numbering scheme. H atoms are drawn as small spheres of arbitrary radii. Displacement ellipsoids are drawn at the 50% probability level.

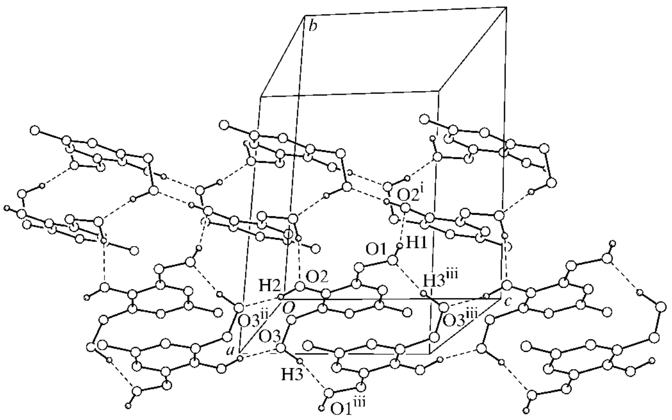


Figure 2
View of the packing in (I). H atoms have been omitted for clarity, except for those involved in hydrogen bonding. The hydrogen bonds are shown as dashed lines. [Symmetry codes: (i) $x, \frac{1}{2}-y, \frac{1}{2}+z$; (ii) $1-x, -y, -z$; (iii) $1-x, -y, 1-z$.]

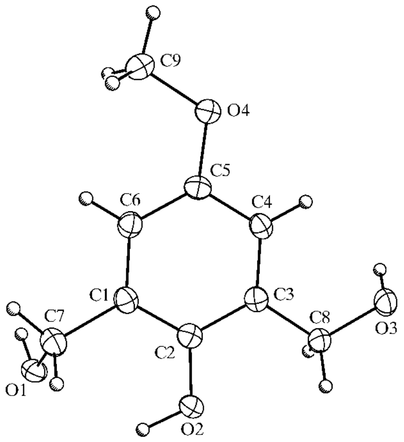


Figure 3
View of the molecule of (II), showing the atom-numbering scheme. H atoms are drawn as small spheres of arbitrary radii. Displacement ellipsoids are drawn at the 50% probability level.

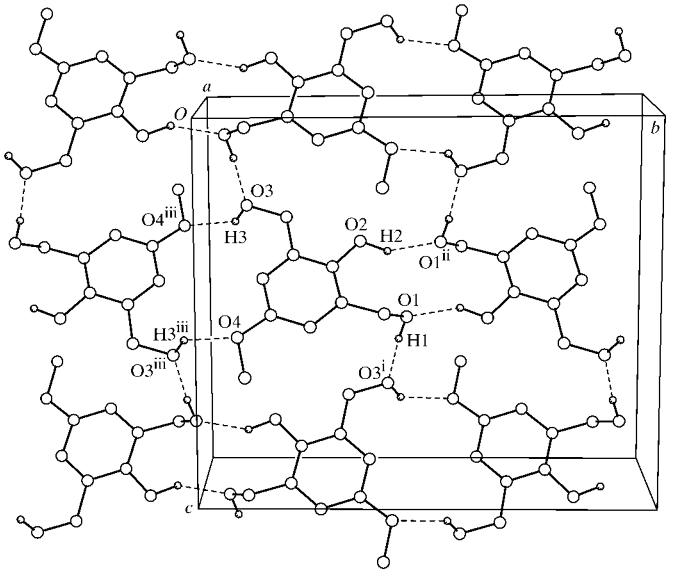


Figure 4
View of the packing in (II). H atoms have been omitted for clarity, except for those involved in hydrogen bonding. The hydrogen bonds are shown as dashed lines. [Symmetry codes: (i) $x, \frac{1}{2}-y, \frac{1}{2}+z$; (ii) $2-x, 1-y, 1-z$; (iii) $2-x, -y, 1-z$.]

interplanar spacing = 4.014 (3) Å, centroid offset = 1.263 (3) Å and shortest interatomic contact C10$\cdots$C14$^{\rm iii}$ = 3.727 (3) Å; rings related by the inversion centre at ($\frac{1}{2}$,1,1); symmetry code: (iii) $1 - x, 2 - y, 2 - z$].

In compound (IV), the *para* substituent is 1-(4-methoxyphenyl)-1-methylethyl, which results in two aromatic rings bound by a C atom, as in the previously reported compound 3,5,3′,5′-tetrahydroxymethyl-4,4′-dihydroxydiphenylmethane (Perrin *et al.*, 1986). Atoms O1, O3 and C12 are located on the same side of the mean plane defined by the phenol ring, at distances of 0.302 (3), 0.828 (3) and 0.821 (3) Å, respectively (Fig. 7). In contrast to (I)–(III), compound (IV) presents an intramolecular hydrogen bond, between the phenolic H atom and atom O3 (Table 4). As a result, each molecule is linked to three neighbours by four intermolecular hydrogen bonds only, atoms O1 and O3 being both donors and acceptors. As in (I) and (III), centrosymmetric dimers are formed, but there is no evidence, in this case, of significant π–π interactions due to the large offset between the two rings [distance between the centroids = 4.881 (3) Å, interplanar spacing = 3.584 (3) Å and centroid offset = 3.313 (3) Å; rings related by an inversion centre at (1,$\frac{1}{2}$,0)]. The hydrogen-bonding network in (IV) gives rise to sheets parallel to the *ab* plane, with the phenol rings roughly perpendicular to it and the methoxyphenyl groups located on each side of the sheets (Fig. 8).

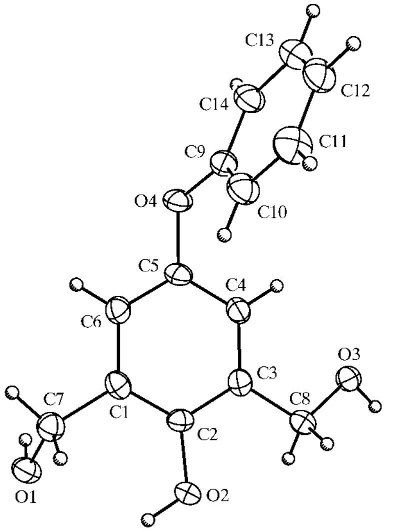


Figure 5
View of the molecule of (III), showing the atom-numbering scheme. H atoms are shown as small spheres of arbitrary radii. Displacement ellipsoids are shown at the 50% probability level.

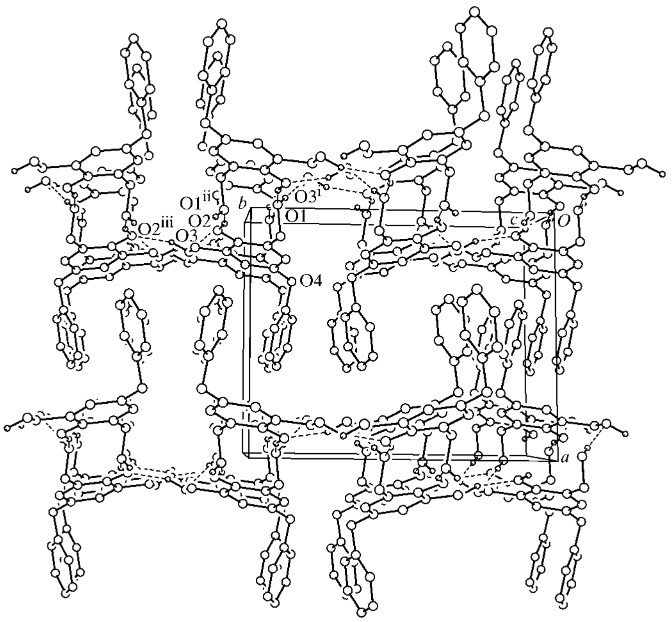


Figure 6
View of the packing in (III), with the *bc* plane horizontal. H atoms have been omitted for clarity, except for those involved in hydrogen bonding. The hydrogen bonds are shown as dashed lines. [Symmetry codes: (i) $-x, 2 - y, 1 - z$; (ii) $-x, 2 - y, -z$; (iii) $x, \frac{5}{2} - y, \frac{1}{2} + z$.]

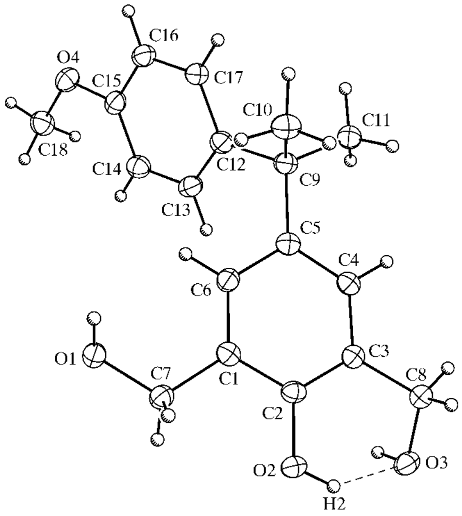


Figure 7
View of the molecule of (IV), showing the atom-numbering scheme. H atoms are drawn as small spheres of arbitrary radii. The intramolecular hydrogen bond is represented by a dashed line. Displacement ellipsoids are drawn at the 50% probability level.

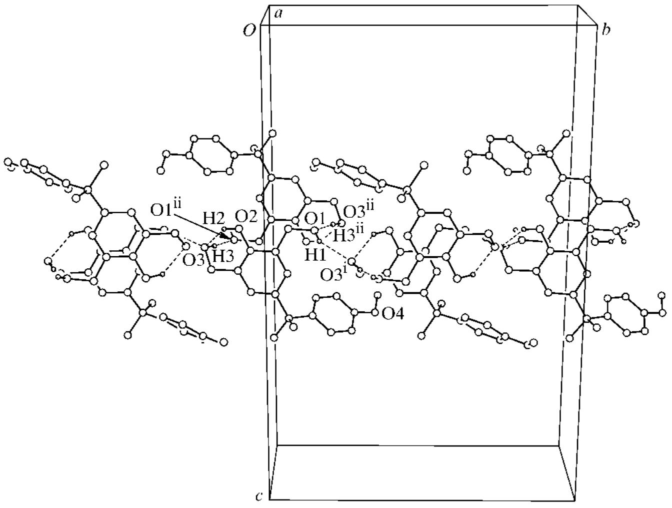


Figure 8
View of the packing in (IV). H atoms have been omitted for clarity, except for those involved in hydrogen bonding. The hydrogen bonds are shown as dashed lines. [Symmetry codes: (i) $\frac{3}{2} - x, \frac{1}{2} + y, z$; (ii) $2 - x, -y, 1 - z$.]

Experimental

Bishydroxymethylation of suitable 4-substituted phenols was carried out in alkaline solution by adapting the literature method of Hanus & Fuchs (1939). Pure samples were obtained by recrystallization from acetone in the case of compounds (I), (II) and (IV), and by recrystallization from chloroform in the case of compound (III).

Compound (I)

Crystal data

$C_9H_{12}O_3$
$M_r = 168.19$
Monoclinic, $P2_1/c$
$a = 8.4545$ (5) Å
$b = 12.5846$ (8) Å
$c = 8.4726$ (5) Å
$\beta = 116.269$ (3)°
$V = 808.36$ (9) Å^3
$Z = 4$

$D_x = 1.382$ Mg m^{-3}
Mo $K\alpha$ radiation
Cell parameters from 4701 reflections
$\theta = 3.1–25.7°$
$\mu = 0.10$ mm^{-1}
$T = 100$ (2) K
Irregular, colourless
0.20 × 0.20 × 0.05 mm

Data collection

Nonius KappaCCD diffractometer
φ scans
4701 measured reflections
1524 independent reflections
1151 reflections with $I > 2\sigma(I)$

$R_{\rm int} = 0.047$
$\theta_{\rm max} = 25.7°$
$h = -10 \rightarrow 10$
$k = -15 \rightarrow 15$
$l = -10 \rightarrow 10$

Refinement

Refinement on F^2
$R[F^2 > 2\sigma(F^2)] = 0.043$
$wR(F^2) = 0.111$
$S = 1.03$
1524 reflections
110 parameters
H-atom parameters constrained

$w = 1/[\sigma^2(F_o^2) + (0.0494P)^2 + 0.1964P]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{\rm max} < 0.001$
$\Delta\rho_{\rm max} = 0.14$ e Å^{-3}
$\Delta\rho_{\rm min} = -0.25$ e Å^{-3}

Table 1
Hydrogen-bonding geometry (Å, °) for (I).

D—H···A	D—H	H···A	D···A	D—H···A
O1—H1···O2$^{\rm i}$	0.84	1.98	2.8010 (17)	166
O2—H2···O3$^{\rm ii}$	0.95	1.78	2.6728 (17)	155
O3—H3···O1$^{\rm iii}$	0.98	1.82	2.7824 (17)	167

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

Compound (II)

Crystal data

$C_9H_{12}O_4$
$M_r = 184.19$
Monoclinic, $P2_1/c$
$a = 4.6556$ (5) Å
$b = 14.5930$ (15) Å
$c = 12.4616$ (9) Å
$\beta = 96.658$ (4)°
$V = 840.92$ (14) Å^3
$Z = 4$

$D_x = 1.455$ Mg m^{-3}
Mo $K\alpha$ radiation
Cell parameters from 4917 reflections
$\theta = 2.8–25.7°$
$\mu = 0.12$ mm^{-1}
$T = 100$ (2) K
Irregular, colourless
0.30 × 0.20 × 0.08 mm

Data collection

Nonius KappaCCD diffractometer
φ scans
4917 measured reflections
1528 independent reflections
1185 reflections with $I > 2\sigma(I)$

$R_{\rm int} = 0.053$
$\theta_{\rm max} = 25.7°$
$h = -5 \rightarrow 5$
$k = -17 \rightarrow 17$
$l = -15 \rightarrow 15$

Table 2
Hydrogen-bonding geometry (Å, °) for (II).

D—H···A	D—H	H···A	D···A	D—H···A
O1—H1···O3$^{\rm i}$	0.90	1.80	2.6951 (19)	175
O2—H2···O1$^{\rm ii}$	0.99	1.84	2.7496 (18)	150
O3—H3···O4$^{\rm iii}$	0.93	2.04	2.7956 (19)	137

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

Refinement

Refinement on F^2
$R[F^2 > 2\sigma(F^2)] = 0.042$
$wR(F^2) = 0.109$
$S = 1.04$
1528 reflections
119 parameters
H-atom parameters constrained

$w = 1/[\sigma^2(F_o^2) + (0.0457P)^2 + 0.2874P]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{\rm max} < 0.001$
$\Delta\rho_{\rm max} = 0.17$ e Å^{-3}
$\Delta\rho_{\rm min} = -0.24$ e Å^{-3}

Compound (III)

Crystal data

$C_{14}H_{14}O_4$
$M_r = 246.25$
Monoclinic, $P2_1/c$
$a = 11.1451$ (11) Å
$b = 13.5515$ (12) Å
$c = 8.1935$ (9) Å
$\beta = 97.486$ (6)°
$V = 1226.9$ (2) Å^3
$Z = 4$

$D_x = 1.333$ Mg m^{-3}
Mo $K\alpha$ radiation
Cell parameters from 9055 reflections
$\theta = 3.0–25.7°$
$\mu = 0.10$ mm^{-1}
$T = 100$ (2) K
Platelet, colourless
0.25 × 0.20 × 0.08 mm

Data collection

Nonius KappaCCD diffractometer
φ scans
9055 measured reflections
2314 independent reflections
1350 reflections with $I > 2\sigma(I)$

$R_{\rm int} = 0.083$
$\theta_{\rm max} = 25.7°$
$h = -13 \rightarrow 13$
$k = -16 \rightarrow 0$
$l = 0 \rightarrow 9$

Refinement

Refinement on F^2
$R[F^2 > 2\sigma(F^2)] = 0.069$
$wR(F^2) = 0.171$
$S = 1.03$
2314 reflections
164 parameters
H-atom parameters constrained

$w = 1/[\sigma^2(F_o^2) + (0.0508P)^2 + 1.3956P]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{\rm max} < 0.001$
$\Delta\rho_{\rm max} = 0.27$ e Å^{-3}
$\Delta\rho_{\rm min} = -0.26$ e Å^{-3}
Extinction correction: *SHELXL*97
Extinction coefficient: 0.016 (3)

Table 3
Hydrogen-bonding geometry (Å, °) for (III).

D—H···A	D—H	H···A	D···A	D—H···A
O1—H1···O3$^{\rm i}$	0.85	1.90	2.727 (3)	164
O2—H2···O1$^{\rm ii}$	0.91	1.78	2.651 (3)	158
O3—H3···O2$^{\rm iii}$	0.96	1.88	2.797 (3)	158

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

Compound (IV)

Crystal data

$C_{18}H_{22}O_4$
$M_r = 302.36$
Orthorhombic, $Pbca$
$a = 7.0604$ (4) Å
$b = 16.4995$ (11) Å
$c = 25.6678$ (17) Å
$V = 2990.1$ (3) Å^3
$Z = 8$
$D_x = 1.343$ Mg m^{-3}

Mo $K\alpha$ radiation
Cell parameters from 16 226 reflections
$\theta = 2.6–25.7°$
$\mu = 0.09$ mm^{-1}
$T = 100$ (2) K
Irregular, colourless
0.35 × 0.20 × 0.08 mm

Data collection

Nonius KappaCCD diffractometer
φ scans
16 226 measured reflections
2824 independent reflections
2188 reflections with $I > 2\sigma(I)$

$R_{\rm int} = 0.064$
$\theta_{\max} = 25.7°$
$h = -8 \rightarrow 8$
$k = -20 \rightarrow 20$
$l = -31 \rightarrow 31$

Refinement

Refinement on F^2
$R[F^2 > 2\sigma(F^2)] = 0.045$
$wR(F^2) = 0.119$
$S = 1.04$
2824 reflections
202 parameters
H-atom parameters constrained

$w = 1/[\sigma^2(F_o^2) + (0.0611P)^2 + 0.9384P]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{\max} < 0.001$
$\Delta\rho_{\max} = 0.25$ e Å^{-3}
$\Delta\rho_{\min} = -0.25$ e Å^{-3}

Table 4
Hydrogen-bonding geometry (Å, °) for (IV).

D—H$\cdots A$	D—H	H$\cdots A$	$D\cdots A$	D—H$\cdots A$
O1—H1$\cdots$O3$^{\rm i}$	0.94	2.08	2.7720 (16)	129
O2—H2$\cdots$O3	0.92	1.95	2.7436 (17)	143
O3—H3$\cdots$O1$^{\rm ii}$	1.00	1.72	2.7095 (17)	169

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

The hydroxy H atoms were found in a difference Fourier map and were treated as riding atoms, with an isotropic displacement parameter ($U_{\rm iso}$) equal to 1.2 times the $U_{\rm eq}$ value of the parent atom. All other H atoms were introduced at calculated positions and were refined as riding, with C—H bond lengths of 0.93 (CH), 0.97 (CH_2) and 0.96 Å (CH_3), and an isotropic displacement parameter ($U_{\rm iso}$) 1.2 (CH and CH_2) or 1.5 (CH_3) times the $U_{\rm eq}$ value of the parent atom.

For all compounds, data collection: *KappaCCD Server Software* (Nonius, 1997); cell refinement: *DENZO–SMN* (Otwinowski & Minor, 1997); data reduction: *DENZO–SMN*; program(s) used to solve structure: *SHELXS*97 (Sheldrick, 1997); program(s) used to refine structure: *SHELXL*97 (Sheldrick, 1997); molecular graphics: *SHELXTL* (Bruker, 1999); software used to prepare material for publication: *SHELXTL* and *PLATON* (Spek, 2000).

Supplementary data for this paper are available from the IUCr electronic archives (Reference: GD1213). Services for accessing these data are described at the back of the journal.

References

Allen, F. H. & Kennard, O. (1993). *Chem. Des. Autom. News*, **8**, 1, 31–37.
Bruker (1999). *SHELXTL*. Bruker AXS Inc., Madison, Wisconsin, USA.
Crisp, G. T., Turner, P. D. & Tiekink, E. R. T. (2000). *Z. Kristallogr. New Cryst. Struct.* **215**, 443–444.
Gutsche, C. D. (1989). *Calixarenes*. Cambridge: The Royal Society of Chemistry.
Hanus, F. & Fuchs, E. (1939). *J. Prakt. Chem.* **153**, 327–336.
Masci, B. (2001). *Calixarenes 2001*, edited by Z. Asfari, V. Böhmer, J. M. Harrowfield & J. Vicens, pp. 235–249. Dordrecht: Kluwer Academic Publishers.
Nonius (1997). *KappaCCD Server Software*. Windows 3.11 Version. Nonius BV, Delft, The Netherlands.
Oehler, D., Thozet, A. & Perrin, M. (1985). *Acta Cryst.* C**41**, 1766–1768.
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.
Perrin, M. & Cherared, M. (1986). *Acta Cryst.* C**42**, 1623–1625.
Perrin, R., Lamartine, R., Vicens, J., Perrin, M., Thozet, A., Hanton, D. & Fugier, R. (1986). *Nouv. J. Chim.* **10**, 179–190.
Sheldrick, G. M. (1997). *SHELXL*97 and *SHELXS*97. University of Göttingen, Germany.
Spek, A. L. (2000). *PLATON*. University of Utrecht, The Netherlands.