Supramolecular Chemistry
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713649759

Design of new host compounds, *cis*-1,4-diphenylcyclohexane-1,4-diol, exo, exo-2,5-diphenylnorbornane-2,5-diol, exo-exo-2,6-diphenylbicyclo[3.3.1]nonane-2,6-diol and their derivatives

Fumio Toda[a]; Koichi Tanaka[a]; Tsunehiro Imai[a]; Susan A. Bourne[b]
[a] Department of Applied Chemistry, Faculty of Engineering, Ehime University, Matsuyama, Ehime, Japan [b] Department of Chemistry, University of Cape Town, Rondebosch, South Africa

To cite this Article Toda, Fumio , Tanaka, Koichi , Imai, Tsunehiro and Bourne, Susan A.(1995) 'Design of new host compounds, *cis*-1,4-diphenylcyclohexane-1,4-diol, exo, exo-2,5-diphenylnorbornane-2,5-diol, exo-exo-2,6-diphenylbicyclo[3.3.1]nonane-2,6-diol and their derivatives', Supramolecular Chemistry, 5: 4, 289 — 295
To link to this Article: DOI: 10.1080/10610279508233956
URL: http://dx.doi.org/10.1080/10610279508233956

SUPRAMOLECULAR CHEMISTRY, Vol. 5, pp. 289–295
Reprints available directly from the publisher
Photocopying permitted by license only

Design of new host compounds, *cis*-1,4-diphenylcyclohexane-1,4-diol, exo, exo-2,5-diphenylnorbornane-2,5-diol, exo-exo-2,6-diphenylbicyclo[3.3.1]nonane-2,6-diol and their derivatives

FUMIO TODA*[a], KOICHI TANAKA[a], TSUNEHIRO IMAI[a] and SUSAN A. BOURNE*[b]

[a]*Department of Applied Chemistry, Faculty of Engineering, Ehime University, Matsuyama, Ehime 790, Japan and* [b]*Department of Chemistry, University of Cape Town, Rondebosch 7700, South Africa*

(Received February 3, 1995)

The title host compounds were designed. Of these, *cis*-1,4-diphenylcyclohexane-1,4-diol (4) showed very high inclusion ability for alcohols and phenols, although its *trans*-isomer (3) showed none. By applying the selective inclusion complexation behaviour of 4, separation of isomers was accomplished. *Rac*-exo,exo-2,5-diphenylnorbornane-2,5-diol (9a) and *rac*-exo,exo-2,6-diphenylbicyclo[3.3.1]nonane-2,6-diol (11a) showed very poor inclusion ability. The optically active derivative of 11a (11b) showed none. In order to determine the reasons for the inclusion tendencies of the newly designed host compounds, molecular and crystal structures were studied by X-ray analysis.

INTRODUCTION

Previously we reported that *trans*-9,10-dihydroxy-9,10-diphenyl-9, 10-dihydroanthracene (**1**) is a very good host compound and includes various kinds of guest compounds.[1] We have attempted to design some new host compounds by simplifying the structure of **1**. This article presents the results of our study.

RESULTS AND DISCUSSION

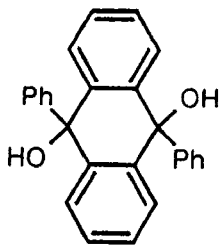
The first new host compound, *trans*-1,4-diphenylcyclohexane-1,4-diol (**3**), which had been designed by removing the two benzo groups from **1**, showed no inclusion ability. However, the *cis*-isomer of **3** (**4**) readily included a number of alcohols and phenols (Table 1). **3** and **4** were prepared by an addition reaction of PhLi to 1,4-cyclohexanedione (**2**).

In order to understand the reason for the difference in the inclusion behaviour of **1** and **3**, and of **3** and **4**, we examined their crystal structures. Details of the data collection and structure refinements are given in Table 2. Final atomic coordinates, anisotropic thermal parameters, bond lengths and angles and tables of observed and calculated structure factors have been deposited. Atomic labelling is according to Fig. 1. Although a 1:2 inclusion compound of **1** and MeOH is constructed by the formation of a hydrogen bonded circle as shown schematically

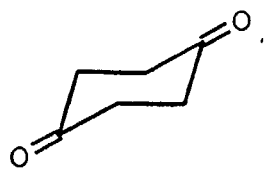
Table 1 Host: guest ratios in the inclusion compounds

	Hosts					
Guest compound	***4***	***9a***	***11a***	***12a***	***12b***	***12c***
MeOH	1:1	1:1	-	-	1:2	-
EtOH	1:1	1:1	-	-	1:2	-
nPrOH	1:1	-	-	-	-	-
iPrOH	1:1	-	-	-	-	-
nBuOH	1:1	-	2:1	-	-	-
iBuOH	1:1	-	1:1	-	-	-
sBuOH	1:1	-	1:1	-	-	-
tBuOH	-	-	-	-	-	-
C_6H_5OH	1:2	1:1	-	1:1	-	2:1
o-MeC_6H_4OH	-	-	-	-	-	-
m-MeC_6H_4OH	1:2	1:1	-	-	-	1:1
p-MeC_6H_4OH	-	-	-	-	-	-
5	-	-	2:1	-	-	-
6	2:1	2:1	2:1	-	-	-
7	1:1	-	1:1	-	-	-
13	-	-	-	-	-	-
14	2:1	-	1:1	-	-	-

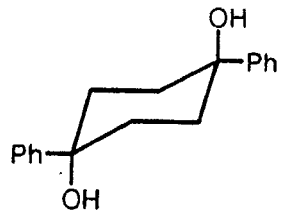
*To whom correspondence should be addressed.



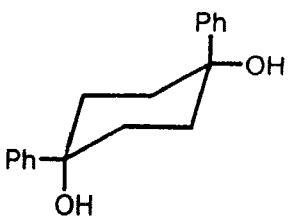
1



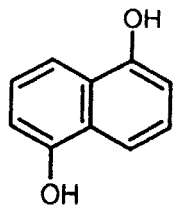
2



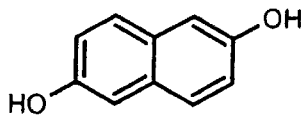
3



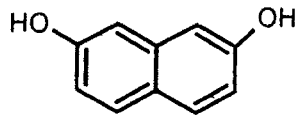
4



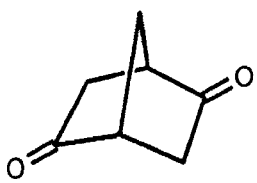
5



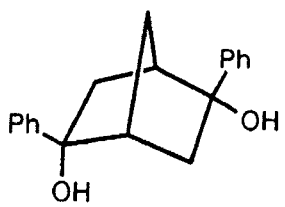
6



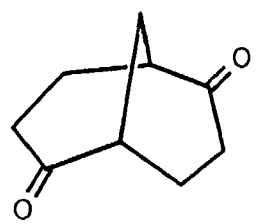
7



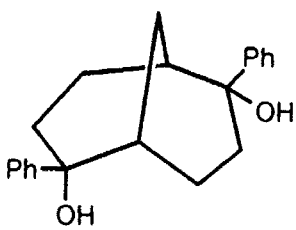
8



9



10

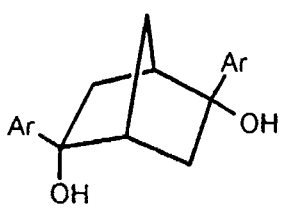


11

a : (rac)-form

b : (+)-form

c : (-)-form



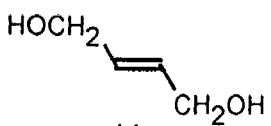
12

a : Ar = p-MeC_6H_4

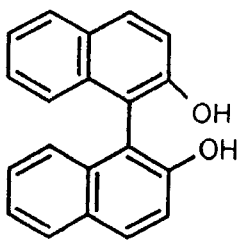
b : Ar = 1-naphthyl

c : Ar = p-PhC_6H_4

13



14



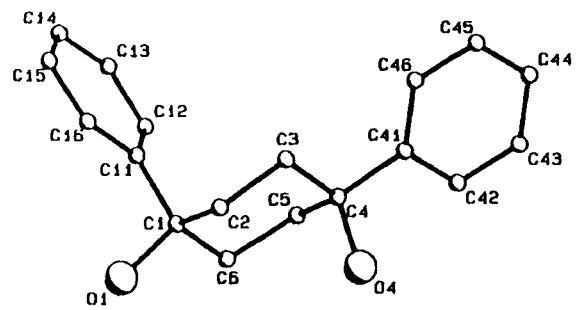
15

Scheme 1

Table 2 Crystal data and selected details of the refinement calculations

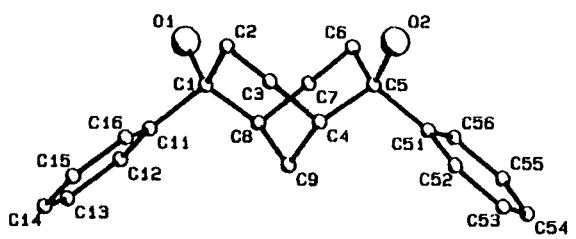
	4 . 6	*4 . 14*	*11a . 14*	*11b*	*3*
Empirical formula	$C_{23}H_{24}O_3$	$C_{38}H_{44}O_5$	$C_{25}H_{32}O_4$	$C_{42}H_{48}O_4$	$C_{36}H_{40}O_4$
Formula weight	348.2	580.73	396.51	616.80	536.68
Space group	$P2_1/n$	$P\bar{1}$	P_{bcn}	$P2_12_12$	$P2_1$
a (Å)	14.617(4)	10.773(2)	12.74(1)	19.691(6)	6.714(2)
b (Å)	6.254(1)	12.075(4)	13.440(7)	19.691(6)	19.80(2)
c (Å)	19.884(7)	14.402(5)	25.06(2)	8.983(9)	10.865(3)
α (°)	90	102.53(3)	90	90	90
β (°)	92.25(2)	102.07(4)	90	90	100.17(2)
γ (°)	90	113.01(3)	90	90	90
V (Å^3)	1816.3(9)	1590.7(8)	4291(5)	3483(4)	1422(2)
Z	4	2	8	4	2
D_c (g cm^{-3})	1.274	1.212	1.228	1.176	1.254
μ (mm^{-1})	0.083	0.079	0.082	0.074	0.080
F(000)	744	624	1712	1328	576
Crystal size (mm)	0.30 × 0.30 × 0.30	0.44 × 0.31 × 0.25	0.50 × 0.50 × 0.38	0.50 × 0.47 × 0.25	0.47 × 0.44 × 0.28
θ range (°)	1 - 25	1 - 25	1 - 25	1 - 25	1 - 25
h,k,l range	±17, 7, 23	±12, ±14, 17	15, 15, 29	23, -23, 10	±7, ±23, 12
Reflections collected	3289	5816	3762	3462	5251
Unique reflections	3192	5574	3762	3462	4986
Parameters	249	451	290	433	387
R1 [I > 2 σ I]	0.0510	0.0854	0.0472	0.0725	0.0463
wR2	0.1382	0.2226	0.1270	0.2007	0.1214
Largest diff. peak and hole (e Å^{-3})	0.21, −0.25	0.42, −0.40	0.26. −0.18	0.39, −0.32	0.42, −0.28

in Fig. 2,[2] **3** forms a linear hydrogen bonded network as depicted in Fig. 3. In the crystal structure of **3**, two crystallographically independent molecules are found in the asymmetric unit. The hydroxyl hydrogens on the molecule labelled A are disordered equally over two positions. The aromatic rings are planar with deviations < 0.1 Å while the central rings of the two molecules are in the chair conformation. The hydroxyl groups are axial to the chair cyclohexane ring. The molecules pack in columns of alternating A and B molecules,



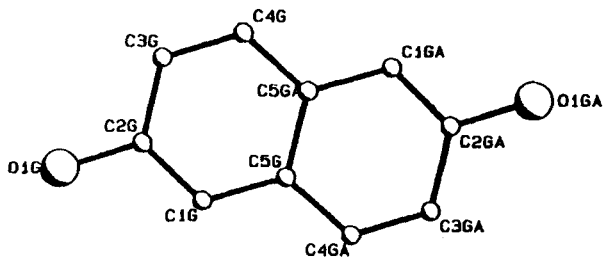
4

(3 = *trans*-isomer)

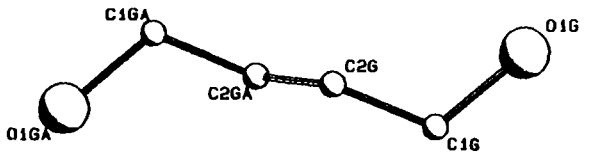


11a

(11b = (+)-form)



6



14

Figure 1 Atomic nomenclature used for crystal structure analysis.

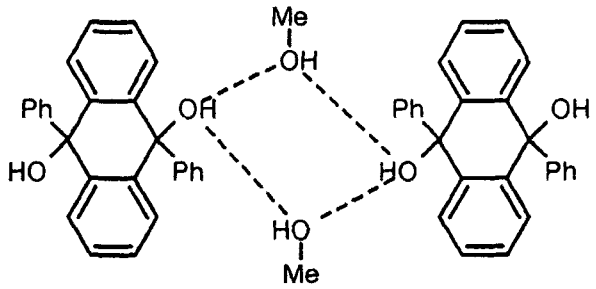


Figure 2 Schematic diagram of hydrogen bonding network in **1**. MeOH.

3

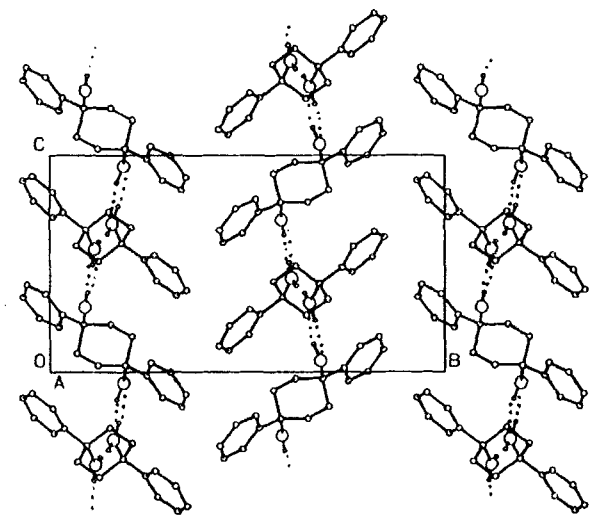


Figure 3 Packing diagram of **3**.

parallel to [001] and held together by hydrogen bonds between O(1A)...O(1B) and O(4A)...O(4B). These columns are in turn held together by hydrogen bonding between O(1A) and O(4A) on molecules adjacent to one another along [100]. This packing is illustrated in Fig. 3 and the hydrogen bonds are fully described in Table 3.

The difference in the inclusion abilities of **1** and **3** is probably due to a steric crowding around the hydroxyl groups of **1**. The X-ray structure of **1**[2] showed that no hydrogen bond can be formed between molecules of **1** because of the steric crowding around the hydroxyl group. When guest molecules are included by **1**, a host-guest hydrogen bond network is formed to stabilise the inclusion compound. On the other hand, steric crowding around the hydroxyl groups of **3** is reduced and molecules of **3** can hydrogen bond to themselves. The inclusion of guest molecules is therefore not necessary to stabilise the crystal structure of **3**. The *cis*-configuration of **4** however prohibits the formation of a linear hydrogen bond network. Instead **4** includes guests in order to construct a stable crystalline structure. X-ray analysis of a *1:1 inclusion* compound of **4** and MeOH found that the

Table 3 Bond distances and angles in hydrogen bonds

Atoms involved $H...O_A$	*Symmetry*	*Distances (Å)* $O_D...O_A$	O_D-H	*Angle (°)* O_D-
4 . 6				
O(1)-H(1)...O(4)	-x, -y, -z	2.793(2)	0.85(3)	174(3)
O(4)-H(4)...O(1G)	x, y, z	2.847(2)	0.89(4)	175(3)
O(1G)-H(1GO)...O(1)	-x, 1-y, -z	2.731(2)	0.89(3)	178(3)
4 . 14				
O(1A)...O(1G)	1-x, 1-y, 1-z	2.752(5)		
O(1A)...O(1B)	-x, 1-y, 1-z	2.811(4)		
O(4A)...O(1G)	x, 1+y, z	2.778(5)		
O(4A)...O(4B1)	-x, 2-y, 1-z	2.816(7)		
O(4A)...O(4B2)	x, y, z	2.944(7)		
O(1B)...O(1B)	-x, 1-y, 1-z	2.839(10)		
O(4B1)...O(4B1)	-x, 2-y, 1-z	2.768(13)		
O(4B2)...O(4B2)	-x, 2-y, 1-z	2.939(11)		
11a . 14				
O(1)...H(1)...O(1G)	x, y, z	2.749(3)	1.03(4)	162(3)
O(1G)-H(1G)...O(1H)	x, y, z	2.678(3)	0.83(4)	156(4)
O(1H)-H(1H)...O(1)	x, y, z	2.716(3)	0.85(4)	167(3)
O(2)-H(2)...O(1G)	x, y, z	2.950(3)	0.85(4)	152(4)
11b				
O(1A)-H(1A)...O(2B)	x, y, z	2.738(8)	0.93(6)	129(5)
O(1B)-H(1B)...O(2A)	1-x, 2-y, z	2.731(8)	0.89(8)	166(6)
O(2A)-H(2A)...O(1B)	1-x, 2-y, z	2.731(3)	1.04(8)	135(6)
O(2B)-H(2B)...O(1A)	x, y, 1+z	2.738(8)	0.87(7)	172(6)
3				
O(1A)-H(1A1)...O(1B)	x, y, z	2.942(3)	0.85(8)	164(6)
O(1B)-H(1B1)...O(1A)	x, y, z	2.942(3)	0.93(5)	158(4)
O(4A)-H(4A1)...O(4B)	x, y, z	2.952(2)	0.75(7)	169(6)
O(4B)-H(4B1)...O(4A)	x, y, z	2.952(2)	0.73(5)	165(5)
O(1A)-H(1A2)...O(4A)	1+x, y, z	2.920(4)	0.92(12)	150(8)
O(4A)-H(4A2)...O(1A)	1+x, y, z	2.920(4)	0.81(8)	169(6)

MeOH linked molecules of **4** into a linear pattern.[2] Although **1** shows high inclusion ability for various kinds of guest compounds, but not for alcohols and phenols[1], **4** shows the opposite tendency and readily includes a number of alcohols and phenols (Table 1).

Grignard reactions of PhMgBr with *rac*-norbornane-2,7-dione (**8**) and *rac*-bicyclo[3.3.1]nonane-2,6-dione (**10**) gave *rac*-exo,exo-2,5-diphenylnorbornane-2,5-diol (**9a**) and *rac*-exo,exo-2,6-diphenyl[3.3.1]nonane-2,6-diol (**11a**) respectively. Both **9a** and **11a** included alcohols and phenols, although fewer than **4** (Table 1). In order to improve the inclusion ability of **9a**, the phenyl group was replaced by other aryl groups. However, all of the resultant derivatives, **12a-c**, included very few guests (Table 1).

Hosts **4**, **9** and **11** include isomeric guests selectively, so they can be used for separating isomers. For example, when a solution of **4** and a 1:1 mixture of *m*- and *p*-cresol in toluene was kept at room temperature, a 1:1 inclusion compound of **4** and *m*-cresol was obtained as colourless crystals, which upon heating in vacuo gave *m*-cresol of 78% purity in 67% yield (Table 4). When the same experiment was carried out using **9a**, *m*-cresol of 99% purity was obtained in 64% yield (Table 4). From a 1:1 mix-

Table 4 Separation of isomers from a mixture by inclusion complexation

Mixture	*Host compound*	*Isolated product*	*Yield (%)*	*Purity (%)*
6 and **7** (1:1)	**4**	**6**	72	87
13 and **14** (1:3)	**4**	**14**	79	93
13 and **14** (1:3)	**11a**	**14**	98	96
m- and *p*-cresol	**4**	*m*-cresol	67	78
m- and *p*-cresol	**9a**	*m*-cresol	64	99

ture of 2,6- (**6**) and 2,7-dihdroxynapthalene (**7**), the former was isolated in 87% purity and 72% yield by a selective inclusion complexation with **4**. Although **4** includes both **6** and **7**, the inclusion complex of **4** with **6** is more stable and is formed more easily. Since **4** does not include 1,5-dihydroxynaphthalene (**5**), **6** and **7** can be isolated from a mixture with **5**. The X-ray crystal structure of the 2:1 inclusion complex of **4** with **6** is shown in Fig. 4. Host and guest are hydrogen bonded to each other to form infinite ribbons of molecules parallel to [100]. There are no close contacts between the ribbons. Each guest hydroxyl moiety is hydrogen bonded to two host molecules in a triangular fashion, as described in Table 3. The aromatic groups are all planar, with atoms deviating less than 0.01 Å from the mean plane. The central ring of the host is a chair, with C(1) and C(4) out of the plane by 0.655(3) and -0.663(3) Å respectively.

Cis- (**13**) and *trans*-2-butene-1,4-diol (**14**) can also be separated by complexation with either **4** or **11a**. From a 1:3 mixture of **13** and **14**, **14** of 93% purity was isolated in 79% yield by complexation with **4**. When the same mixture was treated with **11a**, **14** of 96% purity was isolated in 98% yield (Table 4). The X-ray crystal structures of the 4:1 inclusion complex of **4** with **14** and of the 1:1 inclusion complex of **11a** with **14** are shown in Figs 5 and 6 respectively.

In Fig. 5, there are two host molecules (labelled A and B) and 1/2 a guest molecule in the asymmetric unit. One phenyl ring, attached to C(1B) was found to be disordered over two positions, which refined with site occupancy factors of 0.511 and 0.489. On the same molecule, O(4) was disordered over two positions (s.o.f. 0.522 and 0.478) both of which were involved in the hydrogen bonding scheme described in Table 3 and shown in Fig. 5. The aromatic rings of the host molecules are all planar (r.m.s. deviations < 0.01 Å) and the central ring in each case is a chair, with C(1) and C(4) out of the plane by ≈0.7 Å. Fig. 5 also shows that the host molecules pack in a bilayer, with their hydrophilic faces directed towards the guests.

In Fig. 6, the phenyl rings of the host are planar with maximum r.m.s. deviations of < 0.005 Å. The central part of the molecule comprises two distorted chairs, with C(2) and C(9) out of plane of the one by 0.502(4) and -0.751(3) Å and C(6) and C(9) out of the plane of the second by 0.523(4) and -0.745(3) Å. There are two independent guest molecules (labelled G and H), each on a 2-fold axis. The double bonded central two carbons of the butene guest labelled H are disordered over two positions with refined s.o.f. of 0.554 and 0.446. The packing of this complex (Fig. 6) is similar to that of **4** and **14** (Fig. 5) in that the guests are located in channels between layers of host molecules. The hydrogen bonds illustrated in Fig. 6 are described fully in Table 3.

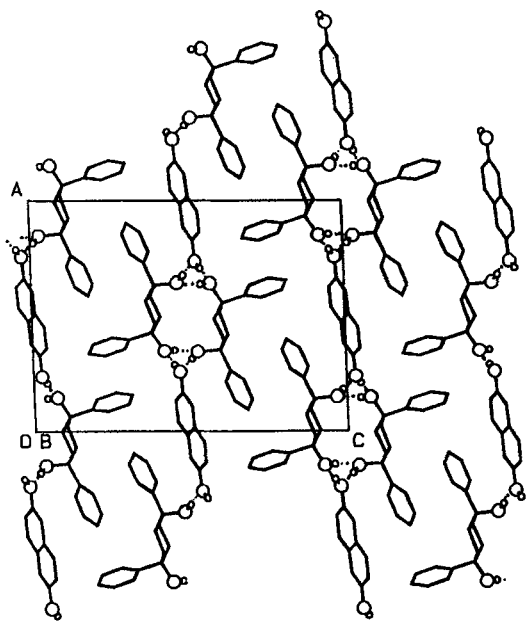


Figure 4 Packing diagram of **4** . **6**.

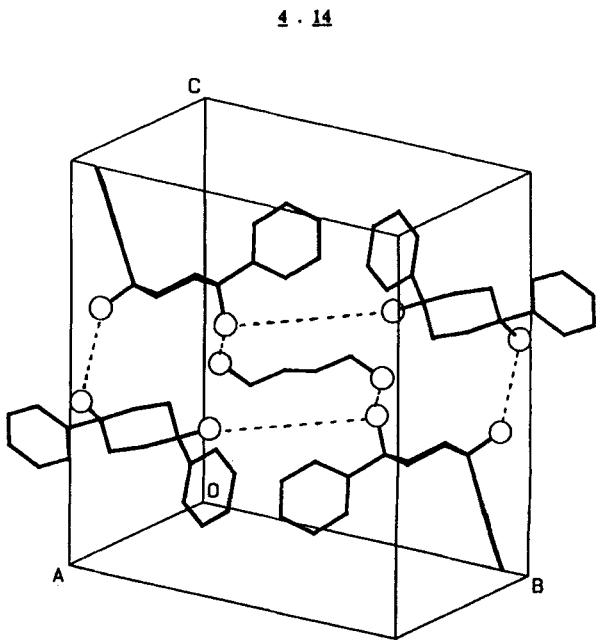


Figure 5 Packing diagram of **4** . **14**.

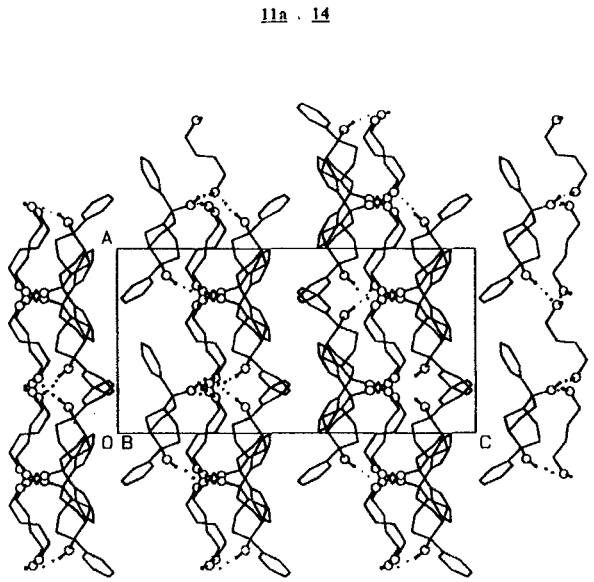


Figure 6 Packing diagram of **11a . 14**.

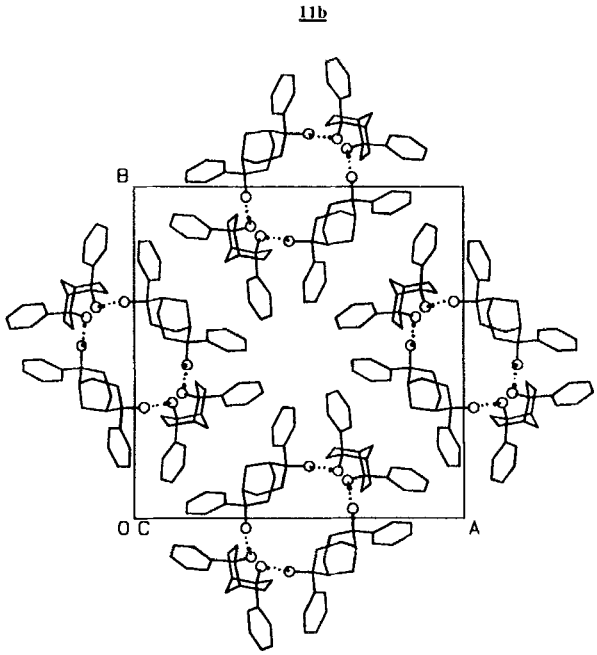


Figure 7 Packing diagram of **11b**.

Optically active derivatives of **11a** (**11b** and **11c**) were prepared by a Grignard reaction of the optically active derivatives of **10a** (**10b** and **10c**) prepared by an optical resolution of **10a** through an inclusion complexation with the chiral host (-)-10,10′-dihydroxy-9,9′-binaphthyl (**15**). We expected optical resolutions of *rac*-guest compounds by complexation with **11b** and **11c**, but neither compound showed any inclusion ability. It is very curious that the *rac*-host **11a** shows some inclusion ability but the chiral hosts **11b** and **11c** do not. In order to discern the reason for the difference, the X-ray crystal structure of the chiral host **11b** was studied. The unit cell appeared to be tetragonal, with $a=b$. However a close examination of the reflections expected to be equivalent revealed the structure to be orthorhombic. This, and the subsequent successful refinement confirmed that the space group is $P2_12_12$. The absolute configuration could not be determined. The molecules pack in tetrameric clusters, hydrogen bonded in a cyclic fashion, as shown in Fig. 7 and described in Table 3. In this cyclic structure, no space is available for a guest.

EXPERIMENTAL

*Preparation of **3** and **4**.* To an ether solution containing phenyl lithium (140 mmol), an ether solution containing 1,4-cyclohexanedione (**2**) (3.8 g, 34 mmol) was added dropwise and the solution was stirred for 1 h and then heated under reflux for 30 min. The reaction mixture was decomposed with dil. HCl and extracted with toluene. The toluene solution was washed with dil. $NaHCO_3$ and dried over Na_2SO_4. Evaporation of the solvent gave crude crystals (5 g) and recrystallisation of these crystals from MeOH gave a mixture of **3** as colourless needles (0.9 g, 10% yield based on **2**) and a 1:1 inclusion complex of **4** and MeOH as colourless prisms (3.5 g, 38% yield based on **2**). The two kinds of crystals were separated mechanically and each was purified by recrystallisation from MeOH. **3** (mp 235-236°C; νOH 3400 and 3550 cm^{-1}). Anal. Calcd. for $C_{18}H_{20}O_2$: C, 80.56; H, 7.51. Found : C, 80.75; H, 7.51%. Heating of the 1:1 MeOH complex of **4** *in vacuo* gave **4** (mp 148-149°C; νOH 3325 and 3375 cm^{-1}). Anal. Calcd. for $C_{18}H_{20}O_2$: C, 80.56; H, 7.51. Found : C, 80.74; H, 7.11%.

*Preparation of **9a** and rac-**12a-c**.* By a Grignard reaction of **8** with PhMgBr in ether, **9a** was prepared in 62% yield (mp 115-116°C, lit. mp 115-116°C; νOH 3280 and 3375 cm^{-1}). Anal. Calcd. for $C_{19}H_{20}O_2$: C, 81.40; H, 7.19. Found : C, 81.32; H, 7.19%. By a similar method, *rac*-**12a-c** were prepared; *rac*-**12a** (mp 155-158°C; νOH 3300 cm^{-1}). Anal. Calcd. for $C_{21}H_{24}O_2$: C, 81.78; H, 7.84. Found: C, 81.82; H, 7.71%; *rac*-**12b** (mp 248-251°C; νOH 3530 and 3570 cm^{-1}). Anal. Calcd. for $C_{27}H_{24}O_2$: C, 85.23; H, 6.36. Found : C, 85.29; H, 6.37%; *rac*-**12c** (mp 179-182°C; νOH 3290 cm^{-1}). Anal. Calcd. for $C_{31}H_{28}O_2$: C86.08; H, 6.52: Found : C, 86.12; H, 6.63%.

*Preparation of **11a**.* Reaction of **10**[4] and three molar amounts of PhMgBr in ether by the usual method gave **11a** after recrystallisation from toluene-hexane, in 33% yield (mp 140-142°C; νOH 3320 cm^{-1}). Anal. Calcd. for $C_{21}H_{24}O_2$: C, 81.78; H, 7.84. Found : C, 81.77; H, 7.94%.

*Preparation of **10b** and **10c** by optical resolution of **10a** through complexation with **15**.* When a solution of **10a**

(1.5 g, 10 mmol) and **15** (1.85 g, 6.5 mmol) in toluene (40 ml) was kept at room temperature for 12 h, a 1:1 inclusion complex of **15** and **10b** was obtained (2.2 g). Recrystallisation of the complex from toluene gave the pure complex (1.75 g) which upon heating at 150°C/3 mm Hg gave **10b** of 92% ee (0.61 g, 81% yield; mp 138-150°C) by sublimation. Anal. Calcd. for $C_{29}H_{26}O_4$: C, 79.43; H, 5.98. Found : C, 79.51, H, 6.05%. From the filtrate left after the separation **10c** of 70% ee (0.6 g, 80% yield) was isolated by sublimation. By repeating the complexation of **10b** of 92% ee and **15**, **10b** of 100% ee was obtained as colourless crystals (mp 158°C; $[\alpha]_D$ +213.5° (*c*. 2.34, dioxane)). Recrystallisation of the **10c** of 70% ee from toluene gave **10c** of 98% ee (mp 157°C; $[\alpha]_D$ -213.3° (*c* 2.39, dioxane)).

*Preparation of **11b** and **11c***. Reaction of **10b** of 100% ee and three molar amounts of PhMgBr in THF by the usual method gave **11b** in 45% yield (mp 140-142°C; $[\alpha]_D$ -3.2° (*c* 1.01, dioxane)). Anal. Calcd. for $C_{21}H_{24}O_2$: C, 81.78; H, 7.84. Found : C, 81.79; H, 7.87%. By the same method, **11c** of 98% ee was obtained from **10c** of 98% ee in 50% yield (mp 140-145°C; $[\alpha]_D$ +3.1° (*c* 1.06, dioxane)). Anal. Calcd. for $C_{21}H_{24}O_2$: C, 81.78; H, 7.84. Found : C, 81.77; H, 7.99%.

General procedure for host-guest inclusion complexation. Host-guest inclusion complexes were prepared by recrystallisation of host compounds from the liquid guest compounds. When the guest is a solid, both the host and guest compounds were recrystallised from a solvent which is not included. The host:guest ratios were determined by ^{1}H NMR spectra and elemental analysis.

*Separation of **6** and **7** by complexation with **4***. When a solution of **4** (210 mg, 0.78 mmol) and a 1:1 mixture of **6** and **7** (125 mg, 0.78 mmol) in AcOEt (5 ml) was kept at room temperature for 6 h, a 2:1 inclusion complex of **4** and **6** was formed as colourless needles (220 mg, 80% yield), which upon heating at 200°C/1 mm Hg gave **6** of 87% purity (45 mg, 72% yield). The purity of **6** was determined by gas chromatography.

*Separation of **13** and **14** by complexation with **4** or **11a***. When a solution of **4** (0.91 g) and a 1:3 mixture of **13** and **14** (0.2 g) in AcOEt (5 ml) was kept at room temperature for 12 h, a 4:1 inclusion complex of **4** and **14** was obtained (mp 137-140°C), which upon heating at 120°C/3 mm Hg gave **14** of 93% purity (0.12 g, 79% yield). When a solution of **11a** (1 g) and a 1:3 mixture of **13** and **14** (0.46 g) in AcOEt (3 ml) was kept at room temperature for 5 h, a 1:1 inclusion complex of **11a** and **14** was obtained (mp 115-116°C), which upon heating at 120°C/3 mm Hg gave **14** of 96% purity (0.28 g, 98% yield). In both cases, the purity of **14** was determined by gas chromatography.

*Separation of m- and p-cresol by complexation with **4** or **9a***. When a solution of **4** (0.5 g) and a 1:1 mixture of *m*- and *p*-cresol (0.8 g) in toluene (3 ml) was kept at room temperature for 12 h, a 1:1 inclusion complex of **4** and *m*-cresol was obtained as colourless crystals, which upon heating at 100°C/3 mm Hg gave *m*-cresol of 78% purity (0.27 g, 67% yield). When a solution of **9a** (0.5 g) and a 1:1 mixture of *m*- and *p*-cresol (0.38 g) in toluene (5 ml) was kept at room temperature for 6 h, a 1:1 inclusion complex of **9a** and *m*-cresol was obtained as colourless crystals. The crude crystals were recrystallised from toluene (3 ml) and then heated at 100°C/3 mm Hg to give *m*-cresol of 99% purity (0.12 g, 64% yield). The purity of *m*-cresol was determined by gas chromatography.

Crystal structure determination. The intensity data were obtained at room temperature (21 °C) on an Enraf-Nonius CAD4 diffractometer equipped with a graphite monochromator and using the ω-2θ technique. Data reduction included corrections for background, Lorentz and polarisation effects. Reference reflections measured at intervals of approximately 60 minutes showed no significant changes in intensity. The unit cell parameters were refined by the least squares method, using 24 strong reflections in the range $17 \geq \theta \geq 16°$. Crystal data and some experimental details are summarised in Table 2.

The structures were solved by direct methods, using SHELXS.[5] Difference electron density and full-matrix least squares (based on F_o^2) using SHELXL-93[6] were then used for completion and refinement of the structure models. The hydroxyl hydrogens were located in difference electron density maps (except for **4 . 14** where they were omitted) and allowed to refine isotropically. All other hydrogens were generated in geometrically assumed positions after each cycle of the refinement calculations. The non-hydrogen atoms were refined anisotropically. Further details of the final refinements are given in Table 2.

ACKNOWLEDGEMENTS

F. T. and K. T. gratefully acknowledge the Ministry of Education, Science and Culture, Japan for the Grant-in-Aid for Scientific Research on Priority Areas, No 06242101.

REFERENCES

1 Toda, F.; Tanaka, K.; Ulibarri Daumas, G.; Sanchez, M. C. *Chem Lett.* **1983**, 1521; Toda, F.; Tanaka, K.; Mak, T. C. W. *Tetrahedron Lett.* **1984**, *25*, 1359; Toda, F.; *Top. Curr. Chem.* **1987**, *43*, 140.
2 Toda, F.; Tanaka, K.; Nagamatsu, S.; Mak, T. C. W. *Isr. J. Chem.* **1985**, *25*, 346; Toda, F.; Tanaka, K.; Mak, T. C. W. *Bull. Chem. Soc. Jpn.* **1985**, *58*, 2221.
3 Hawkins, R. T.; Hsu, R. S.; Wood, S. G. *J. Org. Chem.* **1978**, *43*, 4648.
4 Schaefer, J. P.; Honig, L. M. *J. Org. Chem.* **1968**, *33*, 2655.
5 Sheldrick, G. M. *Acta. Crystallogr.* **1990**, *A46*, 467.
6 Sheldrick, G. M. *J. Appl. Crystallogr.* In prep.