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

Inclusion Behavior of Bis (hydroxydiphenylmethyl)cyclohexane as a Potential Host Compound

Hisashi Mizutani[a]; Junko Ohta[a]; Ikuko Miyahara[a]; Ken Hirotsu[a]; Koichi Tanaka[b]; Fumio Toda[b]
[a] Department of Chemistry, Graduate School of Science, Osaka City University, Osaka, Japan [b] Department of Applied Chemistry, Faculty of Engineering, Ehime University, Matsuyama, Ehime, Japan

To cite this Article Mizutani, Hisashi , Ohta, Junko , Miyahara, Ikuko , Hirotsu, Ken , Tanaka, Koichi and Toda, Fumio(2001) 'Inclusion Behavior of Bis (hydroxydiphenylmethyl)cyclohexane as a Potential Host Compound', Supramolecular Chemistry, 13: 1, 53 — 60

To link to this Article: DOI: 10.1080/10610270108034882

URL: http://dx.doi.org/10.1080/10610270108034882

SUPRAMOLECULAR CHEMISTRY, Vol. 13, pp. 53-60
Reprints available directly from the publisher
Photocopying permitted by license only

Published by license under
the Gordon and Breach Science
Publishers imprint.
Printed in Malaysia.

Inclusion Behavior of Bis(hydroxydiphenylmethyl)cyclohexane as a Potential Host Compound

HISASHI MIZUTANI[a,*], JUNKO OHTA[a], IKUKO MIYAHARA[a], KEN HIROTSU[a], KOICHI TANAKA[b] and FUMIO TODA[b]

[a]*Department of Chemistry, Graduate School of Science, Osaka City University, Sumiyoshi-ku, Osaka 558-8585, Japan;* [b]*Department of Applied Chemistry, Faculty of Engineering, Ehime University, Matsuyama, Ehime 790-8577, Japan*

The diol host, *trans*-1,4-bis(hydroxydiphenylmethyl)cyclohexane has a cyclohexane ring as a rigid framework and a bulky hydroxydiphenylmethyl group at both ends of the molecule. This host showed a good inclusion ability to form complex crystals with a variety of guest molecules. The complexes with MeOH, acetone, THF, DMF, MeCN and DMSO were obtained as single crystals suitable for X-ray crystallographic study. X-ray structure determination of these crystals clarified that the host : guest complexes show that the guest-dependent polymorphism and crystal structures are classified into five groups. The shape and size of a guest seem to determine the molecular packing in the complex crystal. The guest molecules are included in the columns or cages formed by the hydrophobic groups (benzene and cyclohexane rings) of the hosts, and hydrogen bonded to OH groups of the hosts.

Keywords: Inclusion compound; Host-guest complex; Diol host; Inclusion phenomena; Polymorphism; X-ray structure

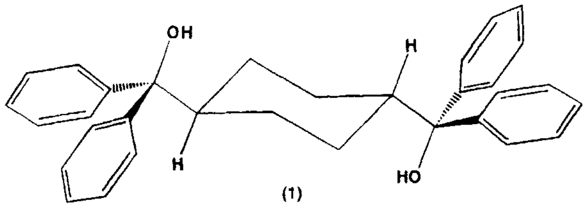
INTRODUCTION

Organic molecules with a rigid framework and having a diarylhydroxymethyl group have been expected to act as host compounds to make inclusion complexes with various guest molecules [1]. Such alcoholic host compounds make it difficult to form a geometrically favorable hydrogen bond between host molecules because the host molecule is rigid and the hydroxyl group is surrounded by a bulky diaryl group. Some host compounds possessing the diarylhydroxymethyl group have been designed and found to work as good host compounds [2-5]. The well-known example of such host molecules is *trans*-4,5-bis(hydroxydiphenylmethyl)-1,3-dioxacyclo-pentane, which is a tartaric acid derivative [6, 7]. This host molecule is characterized by the concentration of hydrophilic groups on the center of the molecule, surrounded by large hydrophobic aryl groups. Previously we reported that *trans*-1,4-bis(hydroxydiphenylmethyl)-cyclohexane (**1**) is a very good host molecule and yields inclusion complexes with a variety of guest species [8]. The diol host **1** has a cyclohexane ring as a rigid framework and bulky diphenylhydroxymethyl groups as substituents

---

*Corresponding author.

at the 1 and 4 positions. Two hydroxyl groups of **1** are located on the opposite side of the molecule. In this respect, **1** is different from the host derived from tartaric acid. In order to elucidate the inclusion behavior of diol host **1**, the structures of inclusion complexes of **1** with various guest molecules have been uncovered by the X-ray crystallographic method.



SCHEME 1

RESULT AND DISCUSSION

The diol host **1** was prepared as described previously [8]. The host **1** was tested for the formation of complexes as single crystals with typical guest molecules (MeOH, EtOH, acetone, THF, MeCN, DMF, DMSO, benzene). Of these guests, all except EtOH and benzene gave complex crystals suitable for X-ray crystallographic study. The single crystal of **1** itself was obtained from the ethanol solution of **1**. X-ray structure determination of these complex crystals showed that the arrangements of host : guest molecules are classified into five groups. The important data characterizing the complexes are summarized in Table I.

The structure of **1**•MeOH complex (form I) has been already reported by us [8], and is briefly described. The host **1** has a crystallographic Ci symmetry with the C4–O1 bond antiparallel to the C1–H bond (O1–C4–C1–C2 = 57.5(4)°, C1–C4–C5–C6 = 64.1(5)° and C1–C4–C11–C12 = −31.7(6)°, and two OH groups of **1** are hydrogen bonded to MeOH oxygens (Fig. 1a). The host molecules stack around crystallographic twofold axes parallel

TABLE I Host : guest complexes of 1 with guests

Complexes	Host : guest ratio	Type of inclusion	Symmetry of column or cage
1 • MeOH	1 : 1	cage	C2
1 • MeOH	1 : 1	column	C2
1 • acetone	1 : 2	column	none
(THF)			
(DMF)			
1 • MeCN	1 : 2	column	2_1
1 • DMSO	1 : 2	cage	Ci

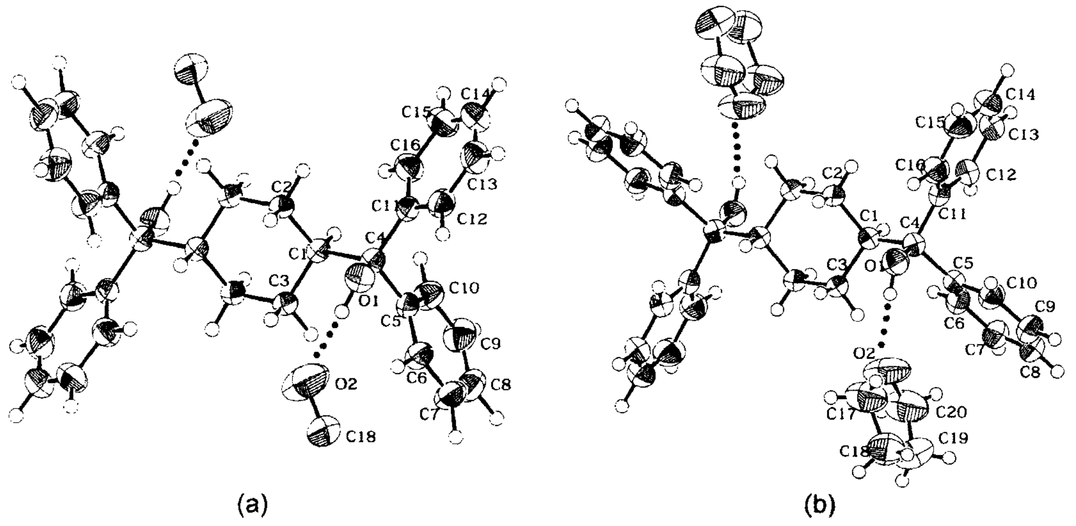


FIGURE 1 Molecular conformation and atom labeling scheme in (a) **1**•MeOH (form I) and (b) **1**•THF. Hydrogen bonds are shown by dotted lines.

to the *b*-axis to make the columns where the guest molecules are linearly arranged on the twofold axis (Fig. 2a). The column actually consists of continuously arranged cages in which the guests are included, since the cyclohexane rings of the hosts make the narrow parts of the column. The hydroxy oxygen of each guest is hydrogen bonded by two OH groups of the two host molecules related by the twofold axis.

The new polymorphic crystal (form II) of **1**•MeOH was obtained and its crystal structure was clarified as shown in Figure 2b. The molecular conformation of **1** is quite similar to that in form I. The host **1** has a crystallographic Ci symmetry with the C4-O1 bond antiparallel to the C1-H bond (O1-C4-C1-C2 = 56.1(2)°, C1-C4-C5-C6 = 68.0(2)° and C1-C4-C11-C12 = −17.3(3)°), and two OH groups of **1** are hydrogen bonded to MeOH oxygens with the distance and angle of O1---O2 = 2.953(7) Å, and ∠O1 – H---O2 = 157°. The host molecules stack around crystallographic twofold axes parallel to the *b*-axis to make inclusion columns where the guest molecules are linearly arranged. MeOH molecules as guests are disordered around the twofold axes with a site occupancy of 0.5, indicating that half the OH groups of hosts are free from hydrogen bonds with the guests. In form I, all OH groups of hosts are involved in hydrogen bonds with the ordered guests. The methyl groups of the guests in forms I and II

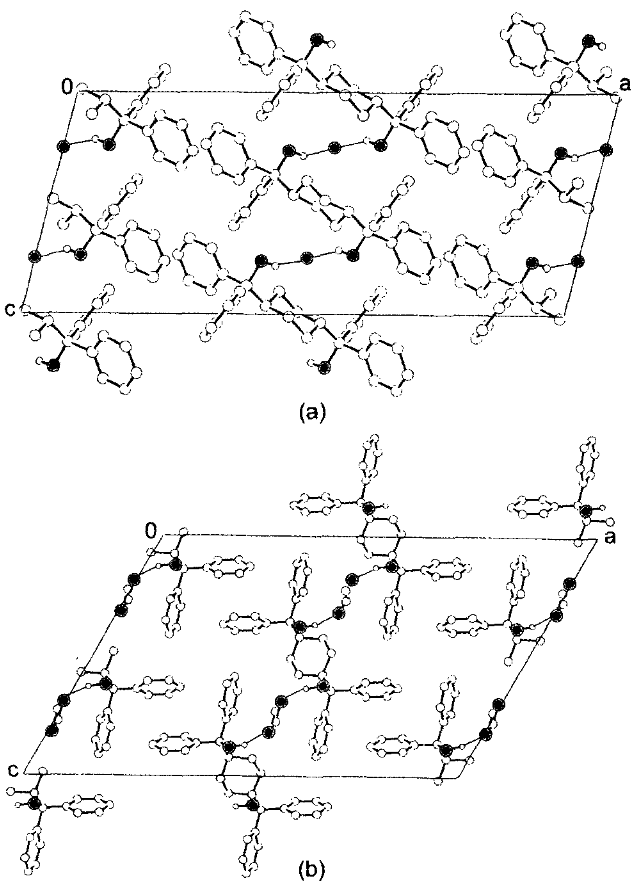


FIGURE 2 The crystal packing of (a) **1**•MeOH (form I) and (b) **1**•MeOH (form II). Oxygen atoms and hydrogen bonds are drawn by full circles and thin lines, respectively.

make van der Waals contacts with the cyclohexane and the phenyl groups of the hosts, respectively.

X-ray diffraction experiments of **1**•THF and **1**•DMF showed that these two crystals are isomorphous with that of **1**•acetone, the structure of which has been already reported [8]. In this report, the description of **1**•THF is given as the representative of these three complexes. The molecular structure and packing are given in Figures 1b and 3, respectively. The host **1** has a crystallographic Ci symmetry with the C4–O1 bond antiparallel to the C1–H bond (O1–C4–C1–C2 = 68.3(2)°, C1–C4–C5–C6 = 12.2(3)° and C1–C4–C11–C12 = –71.1(2)°) and two OH groups of **1** are hydrogen bonded to oxygen atoms of THF with the distance and angle of O1---O2 = 2.889(3) Å, and ∠O1 – H---O2 = 169°. Thus the molecular structure of **1**•THF is similar to those of **1**•MeOH complexes in forms I and II. However, the molecular packing in **1**•THF is quite different from those in **1**•MeOH complexes (Figs. 2 and 3). This is probably because THF is too bulky to be accommodated in the inclusion column of **1**•MeOH (form I or II). The host molecules lie on the crystallographic center of symmetry and stack along the *a*-axis to make the inclusion column, with one host molecule involved in the formation of six inclusion columns. The guests are linearly accumulated in this column with a host : guest ratio of 1 : 2, and each guest is surrounded by one cyclohexane ring and four phenyl groups and is hydrogen bonded to the OH group of the host.

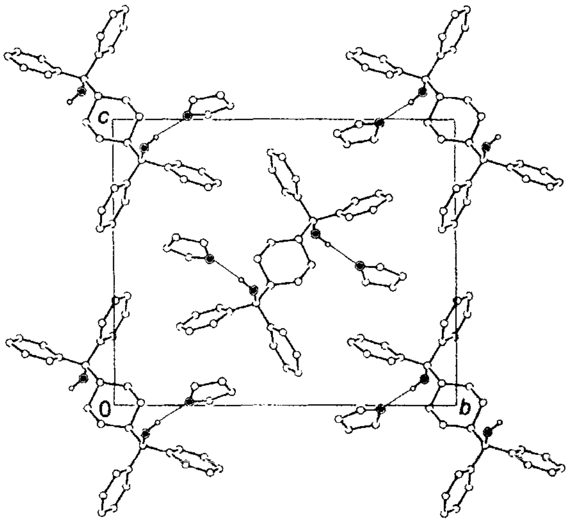


FIGURE 3 The molecular packing of **1**•THF. The structure is isomorphous with those of **1**•acetone and **1**•DMF. Oxygen atoms and hydrogen bonds are drawn by full circles and thin lines, respectively.

X-ray crystal structure analysis of **1**• MeCN showed that the molecular con-formation (O1–C4–C1–C2 = 64.3(4)°, C1–C4–C5–C6 = 33.1(4)° and C1–C4–C11–C12 = –60.0(4)°) and the hydrogen bonding interaction between the host and guest (O1---N = 2.947(4)Å and ∠O1-H---N = 153°) are similar to those found in **1**•MeOH and **1**•THF complexes. Contrary to our expectation, the crystal structure of **1**•MeCN is different not only from that of **1**•THF but also from that of **1**•MeOH (form I or II) as shown in Figure 4. The host molecules lie on the crystallographic center of symmetry and stack along the *b*-axis to make the inclusion columns, with one host molecule involved in the formation of four columns. The guests are arranged along a 2_1 screw axis which goes through the center of the column with a host : guest ratio of 1 : 2. Each guest in the column is surrounded by four phenyl groups and hydrogen bonded to the OH group of the host.

X-ray analysis of **1**•DMSO revealed that the molecular conformation is similar to those found in **1**•MeOH, **1**•THF and **1**•MeCN, but the molecular packing is quite different from any of them. The host **1** has a crystallographic Ci symmetry with the C4–O1 bond antiparallel to the C1–H bond (O1–C4–C1–C2 = 62.9(3)°, C1–C4–C5–C6 = 22.5(4)° and C1–C4–C11–C12 = –61.3(4)°) and OH groups of **1** are hydrogen bonded to the oxygen atoms of DMSO with the distance and angle of O1---O2 = 2.735(3) Å, and ∠O1 – H---O2 = 149°. The host molecules are arranged to make the cages, which encapsulate the guest molecules with a host : guest ratio of 1 : 2 (Fig. 5). Two guest molecules related by a

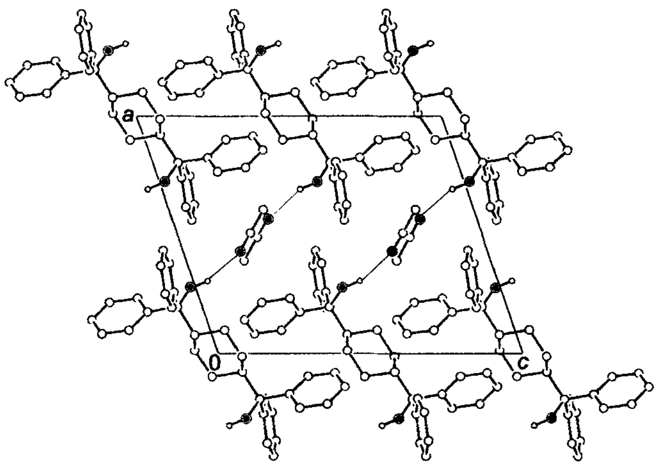


FIGURE 4 The molecular packing of **1**•MeCN. Nitrogen atoms and hydrogen bonds are drawn by full circles and thin lines, respectively.

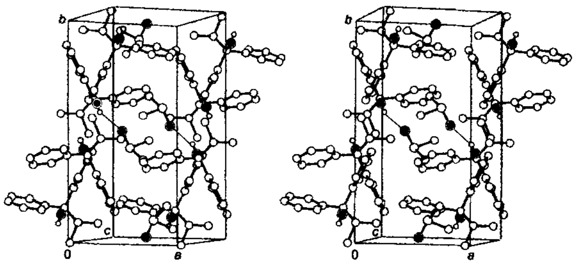


FIGURE 5 Stereoview of the crystal packing of **1**•DMSO. Oxygen atoms and hydrogen bonds are drawn by full circles and thin lines, respectively. One half of each host is drawn for clarity.

crystallographic Ci symmetry are enclosed in the cavity constructed by the eight phenyl groups of six host molecules. Each host molecule is involved in the formation of six cages.

The crystal structure of the host **1** was uncovered by X-ray structure analysis, and is shown in Figure 6. The host **1** has a crystallographic Ci symmetry and the molecular conformation (O1 - C4 - C1 - C2 = 64.1(2)°, C1 - C4 - C5 - C6 = 66.6(2)° and C1 - C4 - C11 - C12 = −41.0(3)°) are similar to those found in the complexes described above. Interestingly, the hydroxy group of **1** is free from hydrogen bond interactions. This is probably because the OH group of **1** is surrounded by bulky substituents at C4, and the approach of two OH groups results in a repulsive interaction between the bulky groups around OH groups. This is the reason why these hosts tend to preferentially make inclusion complexes by forming hydrogen bonds with guest molecules.

The host **1** has roughly the same molecular structure in all the crystal structures described in this report. The torsional angles of O1 - C4 - C1 - C2, C1 - C4 - C5 - C6 and C1 - C4 - C11 - C12 in the hosts are in the ranges of 56.1 to 68.3°, 12.2 to 68.0° and −71.1 to −17.3°, respectively. The molecular skeleton of the host, except for phenyl groups, is rigid as judged from the torsional angles of O1 - C4 - C1 - C2, while the phenyl groups can rotate around C4 - C5 and C4 - C11 bonds, although the rotation is restricted. Two OH groups of **1** are located on the opposite side of the cyclohexane ring with two C - O bonds perpendicular to the ring, and independently interact with the guests to give host:guest molecular complexes. Although the molecular complexes were found to have quite a similar structure to that shown in Figure 1, the assembly of the molecular complexes (crystal structures) showed the guest-dependent polymorphism. The shape and size of a guest seem to determine the molecular packing in the complex crystal: MeOH is the smallest guest, acetone, THF and

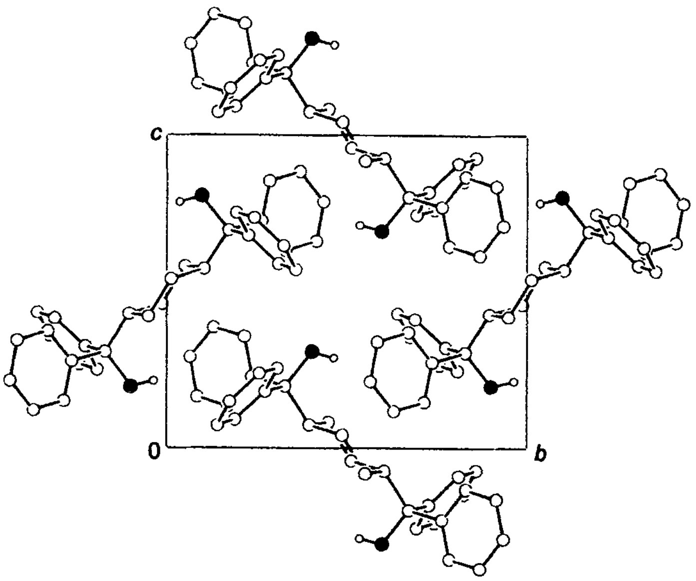


FIGURE 6 The molecular packing of 1. Oxygen atoms are drawn by full circles. The OH groups of 1 are not involved in hydrogen bonds.

DMF are relatively planar with comparable sizes, MeCN is a rod-like molecule, and DMSO is the most bulky guest.

The hydrophobic groups (four benzene and one cyclohexane rings) of the host are involved in the formation of inclusion columns and cages to make van der Waals contacts with the hydrophobic moiety of the guests. It should be emphasized that the bulky phenyl groups at both ends of the host can change the dihedral angles around C4–C5 and C4–C11 to fit the guest molecules. Without the possible rotation of phenyl rings, the host might lose the ability to form inclusion complexes with the various hosts. The benzene and cyclohexane rings are combined in various ways to fit the guest included, forming guest-dependent polymorphic crystals. The host **1** forms the complex crystal with benzene, [8] although the single crystal for X-ray analysis was not obtained. The host:guest ratio of **1**•benzene is 2 : 1 and benzene does not act as a hydrogen bond acceptor for the OH of host **1**, suggesting that the molecular and crystal structures of **1**•benzene are different from those of the complexes given in this report. The versatile host **1** with its rigid skeleton is expected to make additional complex crystals with a variety of guest molecules.

EXPERIMENTAL

X-ray Data

Crystal structure determination of ***1•methanol*** *(form II),* ***1•THF, 1•DMF, 1•MeCN, 1•DMSO and 1.*** Intensity data were collected at room temperature (23°C) on a Rigaku diffractometer with graphite monochromated Cu-Kα radiation and a 12 KW rotating anode generator, using the ω-2θ scan technique. The intensities of three representative reflections were measured after every 150 reflections for all data collections, and no degradation was applied. Empirical absorption corrections were applied for all data [9]. The unit cell parameters were refined by the least-squares method, using 25 carefully centered reflections in the range $57.9° < 2\theta < 59.9°$ for **1**•MeOH, $59.0° < 2\theta < 59.8°$ for **1**•THF, $56.5° < 2\theta < 59.8°$ for **1**•DMF, $56.9° < 2\theta < 59.5°$

TABLE II Crystal data and selected details of the refinement calculations

	1	1•CH_3CN (1:2)	1•DMF(1:2)	1•DMSO(1:2)	1•THF(1:2)	1•MeOH(1:2)
Empirical formula	$C_{32}H_{32}O_2$	$C_{36}H_{38}N_2O_2$	$C_{38}H_{36}N_2O_4$	$C_{36}H_{42}O_4S_2$	$C_{40}H_{48}O_4$	$C_{33}H_{36}O_3$
Formula weight	448.60	530.71	594.79	602.85	592.82	480.65
Space group	$P2_1/n$	$P2_1/c$	$P2_1/c$	$P2_1/c$	$P2_1/c$	C2/c
a(Å)	9.897 (1)	11.798 (2)	5.924 (3)	9.217 (4)	6.096 (1)	28.190 (4)
b(Å)	11.868 (1)	9.568 (1)	18.289 (1)	15.819 (4)	17.9888 (5)	6.006 (4)
c(Å)	10.9915 (9)	14.465 (2)	15.271 (1)	12.249 (4)	15.2545 (8)	17.899 (3)
β(°)	109.799 (7)	109.17 (1)	92.74 (2)	107.09 (3)	96.506 (8)	119.922 (9)
V(Å^3)	1214.7 (2)	1542.3 (4)	1652.7 (7)	1707.0 (10)	1662.1 (2)	2626 (1)
Z	2	2	2	2	2	4
D_c (g/cm^{-3})	1.226	1.143	1.195	1.173	1.184	1.215
μ (cm^{-1})	5.78	5.47	5.72	16.90	5.84	5.95
F(000)	480.00	568.00	640.00	644.00	640.00	1032.00
Crystal size (mm)	0.30 × 0.50 × 1.00	0.20 × 0.20 × 0.35	0.50 × 0.10 × 0.10	0.50 × 0.20 × 0.20	0.20 × 0.20 × 0.20	0.23 × 0.22 × 0.40
2θ range (°)	6.0–120.2	6.0–120.1	6.0–120.2	6.0–120.1	6.0–120.1	6.0–120.1
h, k, l range	11, 13, 12	13, 10, 16	6, 20, 17	10, 17, 13	6, 20, 17	31, 6, 20
Unique reflections	1921	2467	2561	2660	2568	2179
Reflections with $I > 2\sigma$ (I)	1560	1462	1681	2018	1985	1365
Parameters	218	245	263	254	263	172
RI[$I > 2\sigma$ (I)]	0.044	0.055	0.045	0.062	0.052	0.044
wR2	0.064	0.083	0.058	0.096	0.079	0.065
Largest diff. Peak and hole (e Å^{-3})	0.10, −0.21	0.32, −0.16	0.12, −0.19	0.63, −0.35	0.13, −0.25	0.17, −0.23

for **1**•MeCN, 59.0° < 2θ < 59.9° for **1**•DMSO and 59.2° < 2θ < 60.0° for **1**•MeOH.

The structures were solved by direct methods [10], and expanded using Fourier techniques [11]. Full matrix least-squares refinements with anisotropic temperature factors for non-hydrogen atoms and isotropic temperature factors for hydrogens converged to conventional crystallographic discrepancy indexes (R1) of 0.044, 0.052, 0.045, 0.055, 0.062 and 0.044 for **1**•MeOH (form II), **1**•THF, **1**•DMF, **1**•MeCN, **1**•DMSO and **1**, respectively. All calculations were performed using the teXsan crystallographic software package [12]. Crystal data and some experimental details are summarized in Table II.

All final atomic coordinates, anisotropic thermal parameters, bond lengths and angles, torsional angles and observed and calculated structure factors have been deposited.

Acknowledgements

K. H. gratefully acknowledges the Ministry of Education, Science, Sports, and Culture, Japan for Grant-in Aid for Scientific Research on Priority Areas, No 11133254.

References

[1] Toda, F., Top. (1987). *Top. Curr. Chem.*, **140**, 43.
[2] Toda, F. and Akagi, K. (1968). *Tetrahedron Lett.*, p. 3695.
[3] Toda, F., Tanaka, K., Wang, Y. and Lee, G.-H. (1986). *Chem. Lett.*, p. 109.
[4] Bourne, S. A., Caira, M. R., Nassimbeni, L. R., Sakamoto, M., Tanaka, K. and Toda, F. (1994). *J. Chem. Soc.*, Perkin Trans. 2, 1899.
[5] Bourne, S. A., Gifford Nash, K. L. and Toda, F. (1996). *J. Chem. Soc.*, Perkin Trans. 2, 2145.
[6] Seebach, D., Beck, A. K., Imwinkelried, R., Roggo, S. and Wammacott, A. (1987). *Helv. Chim. Acta*, **70**, 954.
[7] Toda, F. and Tanaka, K. (1988). *Tetrahedron Lett.*, **29**, 551.
[8] Toda, F., Fujii, Y., Stein, Z., Goldberg, I., Miyahara, I. and Hirotsu, K. (1997). *Supramol. Chem.*, **8**, 113.
[9] Walker, N. and Stuart, Z. (1983). *Acta Crystallogr.*, **39**, 158.
[10] Sheldrick, G. M., In: *Crystallographic Computing* 3, Eds. Sheldrick, G. M., Kruger, C. and Goddard, R. Oxford University Press, 1985, pp. 175–189.
[11] Beursken, P. T., Admiraal, G., Beurskens, G., Bosman, W. P., Garcia-Granda, S., Gould, R. O., Smits, J. M. M. and Smykalla, C. (1992). The DIRDIF program system, *Technical Report of the Crystallography Laboratory*, University of Nijmengen, The Netherlands.
[12] teXsan: Crystal Structure Analysis Package, Molecular Structure Corporation (1985) and (1992).