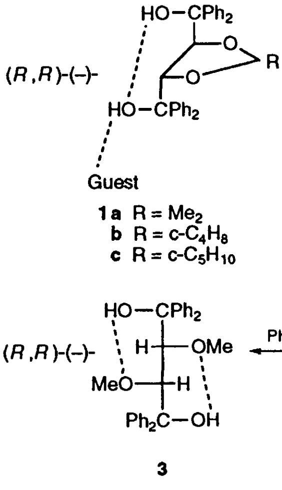
Structure and Inclusion Characteristics of (*R*,*R*)-(−)-2,3-Dimethoxy-1,1,4,4-tetraphenylbutane-1,4-diol

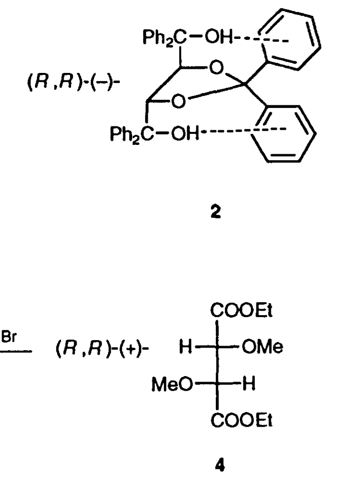
Fumio Toda,*[a] **Koichi Tanaka,**[a] **Zafra Stein**[b] **and Israel Goldberg***[b]
[a] *Department of Applied Chemistry, Faculty of Engineering, Ehime University, Matsuyama, Ehime 790, Japan*
[b] *School of Chemistry, Sackler Faculty of Sciences, Tel-Aviv University, 69978 Ramat-Aviv, Israel*

The title host compound showed very low guest-inclusion ability because of the presence in the host of an intramolecular hydrogen bond between the hydroxy and methoxy group and the absence of intermolecular hydrogen bonds with the guest compound. The X-ray structure of a 2:1 channel-type inclusion compound of the title host and *rac*-limonene guest has been studied.

The diol host compounds (**1a–c**), which had been derived from tartaric acid,[1,2] have been shown to have highly enantioselective inclusion ability towards various guest compounds,[3–6] and have been found quite useful for enantioselective topochemical reactions.[7,8] Moreover, it has been clarified that these hosts are conformationally rigid owing to acetal ring closure and intramolecular hydrogen bonding between the two OH groups. The hydrogen-bonded site within each species is further accessible to, and capable of interacting with, polar guest moieties, thus inducing effective host–guest inclusion complex formation.[9,10] Recent investigations of a closely related host system (**2**) have revealed that this host displays a considerably lower affinity towards complex organic guests. It has been shown that in this case the hydroxy sensor groups are engaged in intramolecular O–H $\cdots \pi$ hydrogen-bonding interactions with the phenyl substituents, which, in conjunction with the spatial shielding provided by the aryl groups, hinder effective association with other species.[11]



1a R = Me$_2$
b R = c-C$_4$H$_8$
c R = c-C$_5$H$_{10}$



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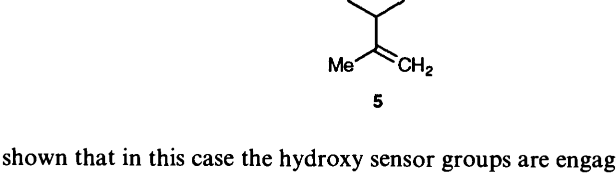
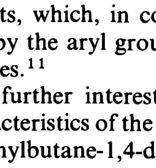


3 **4**



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Within this context, of further interest are the structural features and inclusion characteristics of the host (*R*,*R*)-(−)-2,3-dimethoxy-1,1,4,4-tetraphenylbutane-1,4-diol (**3**) in which there are no ring closure and no bulky substituents in the central part of the molecular framework. In fact, **3** was found to form only a limited number of inclusion compounds with hydrocarbon guests. Suitable examples are provided by its 2:1 complexes with cyclohexane and *rac*-limonene (**5**).[12] In the latter case, no resolution of the guest occurred upon inclusion complex formation. Interestingly, however, slow release of the guest component from the host lattice was detected for the various host–guest combinations. This observation suggests that the solid matrices formed by **3** may be useful for guest release-type applications. In order to elucidate the structural basis of the particular inclusion behaviour of **3**, which is quite different from that exhibited by the host **1a–c**, we have investigated the structure of the 2:1 inclusion crystal of **3** with **5** by X-ray diffraction.

Experimental

(R,R)-(−)-2,3-*Dimethoxy*-1,1,4,4-*tetraphenylbutane*-1,4-*diol* (**3**) *and its* 2:1 *Inclusion Complex with Cyclohexane.*—A solution of (*R*,*R*)-(+)-diethyl 2,3-dimethoxyadipate (**4**)[13] (20 g, 0.085 mol) in dry THF (50 cm^3) was added to PhMgBr prepared from PhBr (67.5 g, 0.43 mol), Mg (10.5 g, 0.43 mol) and dry THF (200 cm^3), and the solution was stirred for 12 h at room temperature. The reaction mixture was combined with aqueous NH$_4$Cl and extracted with toluene. The toluene solution was dried over Na$_2$SO$_4$. The dried toluene solution was evaporated and the residue was combined with cyclohexane (50 cm^3) to give a 2:1 inclusion compound of **3** and cyclohexane as colourless prisms [8.4 g, 20% yield, m.p. 87–90 °C (Found: C, 79.6; H, 7.45. Calc. for C$_{66}$H$_{72}$O$_8$: C, 79.81; H, 7.31%)] which upon heating at 100 °C/20 mmHg for 1 h gave pure **3** as colourless prisms (7.7 g, 20% yield, m.p. 125–126 °C, $[\alpha]_D$ − 153 (*c* 0.8, CHCl$_3$) (Found: C, 79.2; H, 6.85. Calc. for C$_{30}$H$_{30}$O$_4$: C, 79.27; H, 6.65%). The 2:1 ratio of **3** cyclohexane was also determined by thermal gravimetric analysis.

2:1 *Inclusion Compound of* **3** *with* rac-*Limonene* (**5**).—When a solution of **3** (1 g) in *rac*-limonene (**5**) (10 cm^3) was kept at room temperature for 12 h, a 2:1 inclusion compound of **3** and **5** was obtained as colourless prisms [0.8 g, 80% yield, m.p. 105–110 °C (Found: C, 80.3; H, 7.45. Calc. for C$_{70}$H$_{76}$O$_8$: C, 80.43; H, 7.33%)] which upon heating *in vacuo* gave *rac*-limonene (**5**). The 2:1 ratio of **3** and *rac*-limonene was also determined by thermal gravimetric analysis.

Crystal Structure Analysis.—The X-ray diffraction measurements were carried out at room temperature (*ca.* 298 K) on an automated and upgraded Picker diffractometer equipped with a graphite monochromater, using Mo-Kα (λ = 0.7107 Å) radiation. Intensity data were collected out to 2θ = 50° by the ω–2θ scan mode with a constant scan speed of 4.5 deg min^{-1}. Possible deterioration of the analysed crystal was tested by detecting periodically the intensities of three standard reflections from different zones of the reciprocal space, and was found to be negligible during the experiment. A total of 2418 unique reflections with positive intensities was recorded. No corrections for absorption or secondary effects were applied.

*Crystal Data.**—$C_{30}H_{30}O_4{\cdot}C_{10}H_{16}$ (2:1), formula weight 1045.37, monoclinic, space group $C2$, $a = 17.27(1)$, $b = 12.565(1)$, $c = 14.353(1)$ Å, $\beta = 109.49(1)$, $V = 2936.3$ Å^3, $Z = 2$, $D_{calc} = 1.182$ g cm^{-3}, $F(000) = 1120$, μ(Mo-Kα) = 0.71 cm^{-1}.

The structure was solved by direct methods (SHELXS-86),[14] and refined by full-matrix least-squares (SHELX-76),[15] including the positional and anisotropic thermal parameters of the non-hydrogen atoms. The limonene guest (**5**) is located on, and disordered about, the twofold symmetry axis; correspondingly, its geometrical parameters could not be determined with high precision. The structural model used allowed for two alternating positions of the peripheral double bond, and also for different conformational modes of the saturated end of **5**. Most of the hydrogens of **3** were introduced into calculated positions, the methyls being treated as rigid groups. The two hydroxy H-atoms were located directly in difference-Fourier maps. Hydrogens of the disordered guest were not included. The final refinement converged at $R = 0.058$ for 1778 observations having $I > 3\sigma(I)$. At convergence, the peaks and troughs of the difference density map did not exceed 0.21 and -0.18 e A^{-3}, respectively, confirming the correctness of the proposed structure.

Results and Discussion

The molecular and crystal structures of the inclusion compound are illustrated in Figs. 1 and 2, respectively. The crystallographic analysis revealed a unique channel network of the host molecules. The continuous channels extend along the *b*-axis of the crystal, and are accommodated by the limonene guest species (Fig. 2). The channels have a nearly rectangular shape of approximate van der Waals dimensions 4 × 6 Å. Their inner surface consists of the aryl and methyl substituents of the surrounding host molecules. The opening narrows to about 2 Å near the methyls which protrude inward, thus forming a partial enclosure around each guest and hindering its free motion along the channels. Nevertheless, in the absence of specific interactions with the channels walls, and the relatively large cross-sectional diameter of the inter-host channels, the limonene molecules (being pseudo-symmetric with respect to a twofold rotation) exhibit an orientational disorder about the polar C_2 symmetry axis. Consequently, in spite of the asymmetric environment around each guest moiety, the steric constraints of this lattice are insufficient to yield effective resolution of the two similarly shaped enantiomeric forms of limonene.

Inspection of the molecular structure of **3** reveals clearly why the inclusion behaviour of this compound is different from that of hosts **1a–c**. Thus, the –OH sensor groups in **3** are involved in two strong *intra*molecular hydrogen bonds to the methoxy O-atoms in the inner surface of the molecular framework, and are not available as proton donors for intermolecular interaction (Fig. 1). These interactions link positions 1 and 3 [at OH ··· OMe 2.642(9) Å, H ··· O 1.72 Å] and 2 and 4 [at OH ··· OMe 2.690(8) Å, H ··· O 1.73 Å] of the

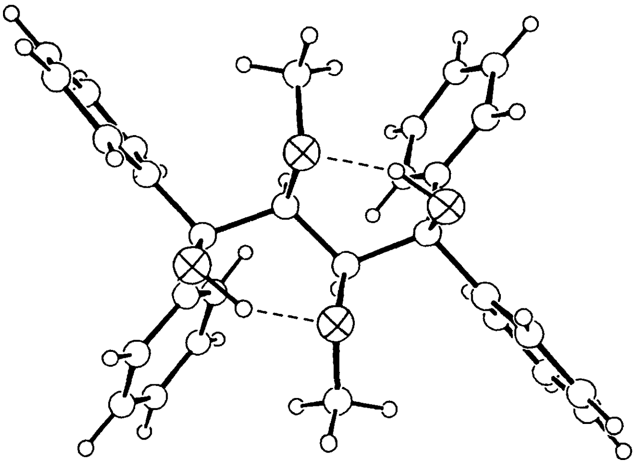

Fig. 1 Illustration of the molecular structure of host **3**, indicating the intramolecular hydrogen bonding. The oxygen atoms are marked by crossed circles, and the hydrogen bonds by dashed lines. The torsion angles in the central C(sp^3) backbone are: C–C–C–C 166.0(6)°, MeO–C–C–OMe 78.0(8)°, HO–C–C–OMe 52.4(7)°, and MeO–C–C–OH 52.8(8)°.

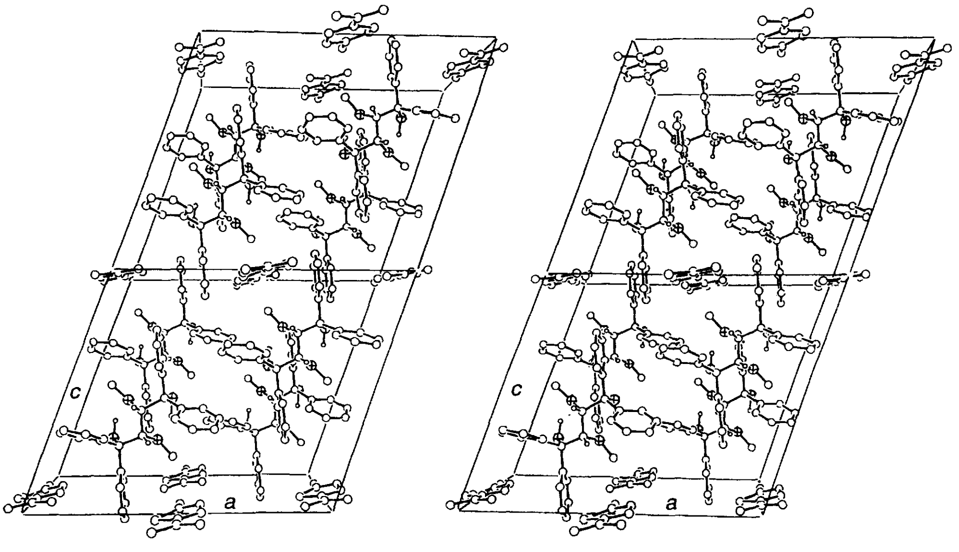

Fig. 2 The crystal structure of the 2:1 inclusion complex of **3** with (±)-limonene, stereoviewed down the *b*-axis of the unit cell. Two unit cells are shown to illustrate better the channel characteristics of the lattice. The inter-host channels extend parallel to the *b*-axis (at $x = 0, z = 0$, and $x \approx 0.5$, $z \approx 0$), and are occupied by orientationally disordered molecules of the (±)-limonene (the latter depicted in their average conformation).

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* Tables of atomic coordinates, bond distances, bond angles and anisotropic thermal parameters for the non-hydrogen atoms have been deposited at the Cambridge Crystallographic Data Centre. For details of the CCDC deposition scheme see 'Instructions for Authors (1993),' *J. Chem. Soc., Perkin Trans. 2*, issue 1.

molecular skeleton. In the resulting structure the outer surface of **3** is lipophilic, the H-bonds incorporating rigidity into the host framework. In the crystal, the host molecules are stacked one on top of the other along the *b*-axis. The lattice thus formed is stabilized mainly by dispersion forces, and to a minor extent also by relatively close contacts (weak hydrogen bonds) between aryl C–H bonds of one species and the hydroxy O-atoms (acting as proton acceptors) of the neighbouring molecules [CH ••• O 3.40(1) Å and H ••• O 2.4 Å].

Channel-type inclusion compounds provide excellent models for chemical reactions in solid matrices, and can be widely used in applications related to controlled-guest release. Indeed, the diffusion of *rac*-limonene (**5**) through the channel network of the crystals analysed was observed to be relatively slow. Control of the guest dynamics can be achieved by suitable structural modifications of either the host (*e.g.*, the size of the alkoxy groups) or the guest components. The crystalline inclusion features of **3**, elucidated above, provide the essential structural basis for further investigation of this subject.

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