Pergamon

Tetrahedron Letters, Vol. 35, No. 28, pp. 5015-5018, 1994
Elsevier Science Ltd
Printed in Great Britain
0040-4039/94 $7.00+0.00

0040-4039(94)01014-5

Guest Selectivity of 1,1,2,2-Tetrakis(4-hydroxyphenyl)ethane

Hiroshi Suzuki

R&D Laboratory for Specialty Chemicals, Nippon Soda Co., Ltd.,
12-54 Goi-Minamikaigan, Ichihara 290, Japan

Abstract: *The inclusion selectivity of 1,1,2,2-Tetrakis(4-hydroxyphenyl)ethane is derived from the hydrogen bonding system in the host-guest aggregates. The mechanism for the inclusion selectivity has been studied by ^{13}C CP/MAS NMR.*

In the last decade, increasing attention has been devoted to the selective inclusion of guest molecules in the formation of inclusion complexes with the purpose of separating mixtures.[1] Some phenolic alkane compounds designed on the basis of phenolic species as simple building blocks are useful to this end, and abilities of some compounds to act as hosts for several molecules have been already pointed out.[2] We have recently found that 1,1,2,2-tetrakis(4-hydroxyphenyl)ethane (**1**) forms crystalline 1:2 or 1:4 inclusion complexes with various n-donors, such as alcohols, carbonyl compounds and so on.[3] The inclusion formation of **1** is chiefly derived from hydrogen bonding interactions between the host and guest molecules.[4] However, it is not understood in detail yet how the phenolic alkane compounds such as **1** recognizes guest molecules and includes them. In this paper, we report the remarkable guest selectivity of **1** derived from solvent competition experiments, and discuss the relationship between the inclusion mode and the inclusion selectivity.

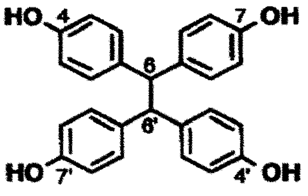
Competitive incorporations of guest molecules were studied by recrystallization of **1** from two-component solvent mixtures.[5] The results are summarized in Table 1. In many cases, **1** showed strong affinity towards one guest in the solvent mixtures. For example, in combination with potential guests, which differed from each other in the nature of functional group, highly selective inclusion phenomena of **1** were observed (Entries 2, 3, 4, 5, 6, and 7 in Table 1). However, in combination with homologous compounds (Entries 8, 10, 13, and 14 in Table 1), **1** did not discriminate the one from the other. The hydrogen bonding interactions between the host and guest molecules are estimated to play an important role in the inclusion formation of **1**.[4] Considering the hydrogen bonding modes between the host and guest molecules, it helps to understand how **1** perceives each of the components in the mixtures. In the hydrogen bond formation with **1**, the n-donors such as acetonitrile, acetone, pyridine and cyclic ethers are able to act as a hydrogen acceptors toward the phenolic hydroxyl groups of **1**. In contrast, pyrrole, which is a weak acid, is able to act predominantly as a hydrogen donor, while alcohols with one hydroxyl group can act as both hydrogen donor/acceptor toward them.[4] This suggests that there are different inclusion modes for the inclusion complexes of **1** with alcohols and the other guests. But for the inclusion complexes of **1** with the individual guest species, similar inclusion formation with similar host-guest associative patterns are expected. The host **1** did not succeed in discriminating between different species such as the solvent mixtures of acetone/acetonitrile, which are similar to each other in the characteristics of hydrogen bonding moieties (Entry 1 in Table 1). This fact demonstrates that the inclusion selectivity of **1** is closely connected with the hydrogen bonding modes based on the hydrogen donor/acceptor relationship between the host and guest molecules in the inclusion formation.[6] On the other hand, interestingly, in combination with homologous but differently branched (Entry 11 in Table 1), lengthened (Entry 9 in Table 1), or bulked compounds (Entry 12 in Table 1), several selective inclusion phenomena were observed, illustrating strict discrimination effects regarding the size and shape of guest molecules. These phenomena indicate that the inclusion formation is strongly influenced by the structure of the guest molecules, and the complex-forming capability and selectivity of **1** depends not only on chemical but also on steric interactions between the host and guest molecules.

Table 1. Selective guest inclusion of **1** from two-component solvent mixtures

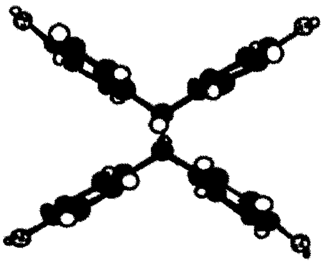
Entry	Recrystallization solvent mixture (I / II)[a)]	Host : I : II molar ratio[b)]
1	acetone / acetonitrile	2 : 3 : 1
2	acetone / methanol	1 : 2 : 0
3	acetone / 2-propanol	1 : 2 : 0
4	acetonitrile / methanol	1 : 2 : 0
5	acetonitrile / 2-propanol	1 : 2 : 0
6	pyridine / methanol	1 : 4 : 0
7	pyrrole / methanol	1 : 2 : 0
8	tetrahydrofuran / 1,4-dioxane	1 : 2 : 2
9	1-propanol / methanol	1 : 0 : 2
10	1-propanol / ethanol	2 : 1 : 1
11	1-propanol / 2-propanol	1 : 0 : 2
12	2-propanol / methanol	1 : 0 : 2
13	2-propanol / ethanol	2 : 1 : 3
14	methanol / ethanol	2 : 1 : 1

a) Equimolar ratio. b) Determined by NMR integration.

In order to clarify the relationship between the inclusion mode and the inclusion selectivity, ^{13}C NMR spectra of the free host **1** and seven inclusion complexes of **1** with methanol (1:2) (**2**), ethanol (1:2) (**3**), 2-propanol (1:2) (**4**), acetonitrile (1:2) (**5**), acetone (1:2) (**6**), tetrahydrofuran (1:4) (**7**) and 1,4-dioxane (1:4) (**8**), were recorded in the solid state using the CP/MAS (cross polarization/magic angle spinning) technique.[7] The spectra are shown in Fig. 1. Concerning the spectra of inclusion complexes with alcohols, the two complexes of **2** and **3** present similar signal patterns except for the signal of each alcohol guest. In the same way, the two spectra of **7** and **8** are also very similar to each other. This indicates that their complexes exist as the same conformer with the same host-guest interactions in the solid state, and accordingly it suggests that **1** is not able to differentiate between their homologs. On the other hand, there are some significant differences among the signal patterns of the phenolic carbon of **1** in the three spectra of b), c) and d). The four phenolic carbon atoms (C4, C4', C7, and C7') of **1** in the spectrum d) appear as a single peak at 154.4 ppm, but in the two spectra of b) and c), they exhibit two peaks of nearly equal intensity for splitting. This difference is probably due to larger steric hindrance in the 2-propanols than methanol

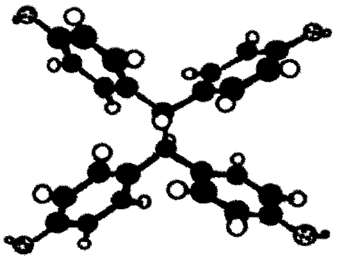


1



(-0.97 kcal/mol)

1a



(-1.77 kcal/mol)

1b

and ethanol. Because the signal patterns of these phenolic carbon of **1** reflect the associative characteristics between the phenolic hydroxyl groups of **1** and guest molecules in the solid state,[4] the observed difference suggest that their inclusion complexes differ from each other in the associative modes based on the hydrogen bond formation between the host and guest molecules. Consequently, it is appropriate to consider that the structural adaptability of the guest molecules in the host-guest aggregates is an important factor

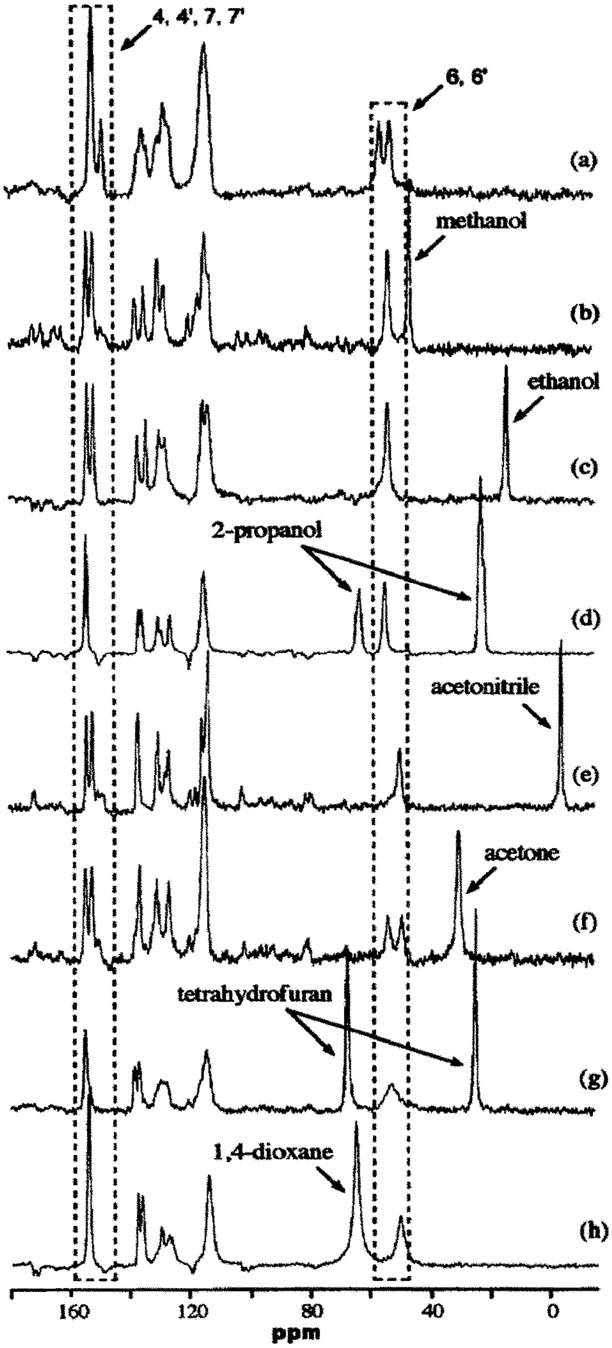


Fig. 1. ^{13}C CP/MAS NMR spectra of the free host **1** and the inclusion complexes of **1** in the solid state at 300 K, a): **1**, b): **2**, c): **3**, d): **4**, e): **5**, f): **6**, g): **7**, h): **8**.

in determining the hydrogen bond formation between the host and guest molecules. Furthermore, notice that there are two types of signal patterns of the methine carbon of **1** in all spectra. One type is observed in each spectrum of **2**—**5**, **7** and **8** as a single peak, indicating that the host **1** exists as a centrosymmetrical conformer of which two methine carbon atoms (C6 and C6') are equivalent in the solid state.[4] Another type is observed in each spectrum of **1** and **6** as two peaks of nearly equal intensity for splitting, suggesting that an unsymmetrical conformation for **1** takes place in the solid state. In an attempt to understand the influence of the conformation of **1** on the inclusion formation, the MM2 molecular mechanics calculation for **1** was carried out.[8] The centrosymmetrical conformer **1a**, which is in accordance with the X-ray structure of the crystalline complex **2**,[4] has higher steric energy (-0.97 kcal/mol) than the optimized conformer **1b** (-1.77 kcal/mol) suggesting an unsymmetrical conformer for the free host **1** from Fig. 1a. These results suggest that a centrosymmetrical conformation for **1** is an intentionally distorted form in the construction of inclusion complexes.

In conclusion, the hydrogen bonding system in the host-guest aggregates plays a decisive role in the inclusion formation in the solid state, and leads to selectively included complexes. It is derived from the hydrogen donor/acceptor relationship between the host and guest molecules which is connected with the functional group characteristics of the guest molecules, and is constructed on the basis of the structural adaptation of the guest molecules with the conformational change of the host molecule in the host-guest aggregates. On the basis of this knowledge, we are now going to design and synthesize other characteristic host molecules.

Acknowledgment: I wish to thank Mr. Hitoshi Matsumoto for NMR spectra measurements. I acknowledge the helpful discussions with Mr. Hideo Takagi and Dr. Mamoru Aizawa.

REFERENCES AND NOTES

1. F. Toda, *Top. Curr. Chem.*, **140**, 43 (1987); K. Tanaka and F. Toda, *Nippon Kagaku Kaishi*, **1988**, 1643; E. Weber, N. Dörpinghaus, and I. Goldberg, *J. Chem. Soc., Chem. Commun.*, **1988**, 1566; E. Weber, K. Skobridis, and I. Goldberg, *J. Chem. Soc., Chem. Commun.*, **1989**, 1195; S. A. Bourne, L. R. Nassimbeni, K. Skobridis, and E. Weber, *J. Chem. Soc., Chem. Commun.*, **1991**, 282.
2. I. Goldberg, Z. Stein, A. Kai, and F. Toda, *Chem. Lett.*, **1987**, 1617; I. Goldberg, Z. Stein, K. Tanaka, and F. Toda, *J. Incl. Phenom.*, **6**, 15 (1988); T. Sone, Y. Ohba, and H. Yamazaki, *Bull. Chem. Soc. Jpn.*, **62**, 1111 (1989); I. Goldberg, Z. Stein, K. Tanaka, and F. Toda, *J. Incl. Phenom. Mol. Recognit. Chem.*, **10**, 97 (1991); Y. Ohba, K. Moriya, and T. Sone, *Bull. Chem. Soc. Jpn.*, **64**, 576 (1991).
3. H. Suzuki, *Tetrahedron Lett.*, **33**, 6319 (1992).
4. H. Suzuki and H. Takagi, *Tetrahedron Lett.*, **34**, 4805 (1993).
5. Typical solvent competition experiments involved recrystallization of about 100 mg of the host **1** from *ca.* 2 ml of solvent mixture in a stoppered sample bottle.
6. E. Weber and M. Czugler, *Top. Curr. Chem.*, **149**, 45 (1988).
7. The ^{13}C CP/MAS NMR spectra were obtained on a Brucker AMX400 FT NMR spectrometer at a carbon frequency of 100.6 MHz, with a sample spinning speed of 3.5 KHz. Chemical shifts are given relative to an external Me_4Si standard, with glycine as a secondary standard (carboxyl carbon signal at 176.03 ppm).
8. N. L. Allinger, *J. Am. Chem. Soc.*, **99**, 8127 (1977).

(*Received in Japan* 11 *April* 1994; *accepted* 13 *May* 1994)