Shell Closures of Tetrabenzyl Chloride Cavitands with Tetrabenzylthiol Cavitands Provide Carceplexes in which One or Two Guest Molecules are Incarcerated

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Carceplexes form with high structural recognition of their incarcerated guests (2MeOH, MeCN, 2MeCN, EtOH, Me_2NCHO, MeCOEt, or Et_2CO); the physical properties of these complexes depend on the structures of both host and guest.

Previously, we reported the first carceplexes **1·G** as insoluble solids with enforced hollow interiors containing solvent, Cs^+ and/or argon.[1] Later, a new family of soluble carceplexes was prepared that is identical to **2·G** except that four OCH_2O groups linked the 'northern' and 'southern' hemispheres in place of the four CH_2SCH_2 groups of **2**.

Here we report the syntheses and characterization of seven carceplexes of structures **2·G** or **3·G**. The syntheses of which closely follow reported procedures for **4** → **5** → **10** → **11** → **12** → **1·G**,[1] and for **6** → **7** → **13**.[2] The reaction sequences, **13** → **14** → **15** and **8**[3] → **9** → **16** → **17** → **18** went in 40 and 12% overall yields, respectively.† The crucial shell closures were run at moderately high dilution with alkali-metal carbonates as base in solvents we wished to incarcerate (20–32% yields). Each carceplex (except **2**·2MeCN) was purified by chromatography, and gave elemental analyses (C, H, O, S and N when present) individually within 0.3% of theory, and which collectively varied from 99.75 to 100.24%. An attempted run in C_6H_6 gave no **3**·C_6H_6. The runs leading to **2**·2MeOH, **2**·MeCN, or **3**·EtOH made in 1 : 1 (v) MeOH–C_6H_6, 1 : 1 (v), MeCN–C_6H_6, or 1 : 1 (v) EtOH–C_6H_6, respectively, gave no carceplex containing C_6H_6, although molecular models (Corey–Pauling–Koltun) of **2**·C_6H_6 or **3**·C_6H_6 are easily assembled. The absence of such products is interpreted as being an artifact of the S_N2 transition states requiring stabilization by polar solvents in the medium. The run made in MeCN–C_6H_6 led to a 1.2 : 1.0 mixture of **2**·2MeCN to **2**·MeCN (^1H NMR) which was converted to **2**·MeCN by heating (110 °C for 72 h in MeC_6H_5, ^1H NMR). The DCI MS spectra (Me_3C^+ bombardment)[4] of each carceplex (except **2**·$2CH_3CN$) gave the parent as the most abundant ion in both the positive and negative modes except for **2**·MeCN, which provided in the negative mode a substantial M^+ signal, which was not the base peak.

The 500 MHz ^1H NMR spectra of the seven carceplexes in $CDCl_3$ at 25 °C provided interesting structural information. Proton counting of host and guest confirmed the absence of empty host, and corroborated host–guest ratios derived from elemental analyses and mass spectra. In molecular models, **2** and **3** have a long polar C_4 axis and four shorter equatorial C_2

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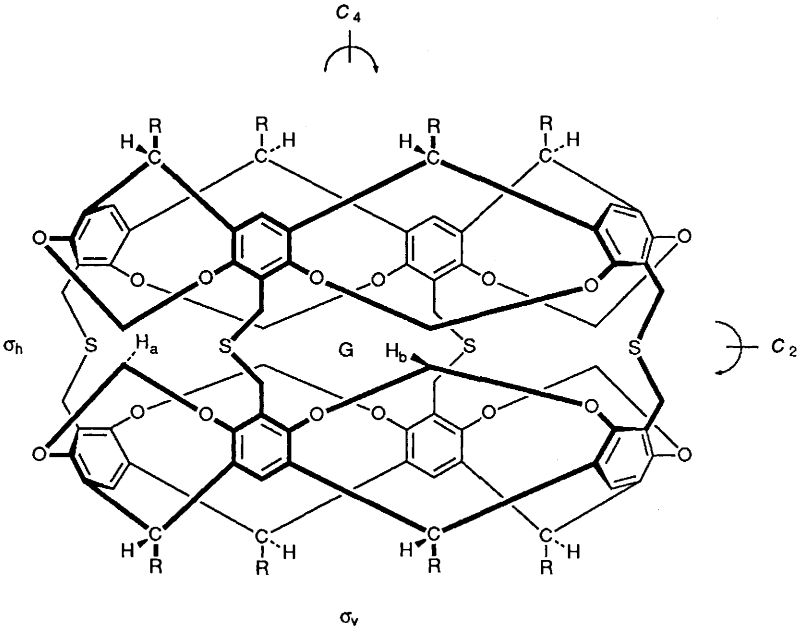
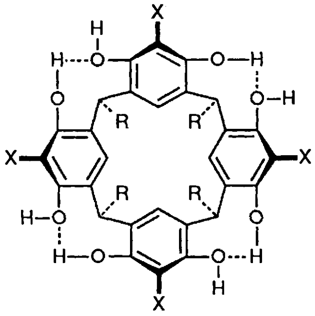
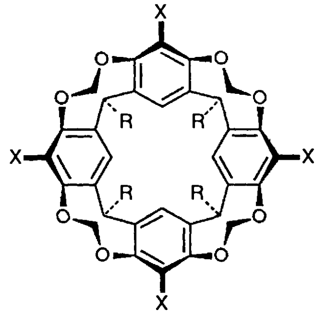
† These new compounds gave C and H elemental analyses within 0.30% of theory, mass spectra with strong $M + H^+$ peaks and the expected ^1H NMR spectra.



1·G, R = Me
2·G, R = $CH_2CH_2C_6H_5$
3·G, R = C_5H_{11}



4, R = Me, X = H
5, R = Me, X = Br
6, R = CH_2CH_2Ph, X = H
7, R = CH_2CH_2Ph, X = Br
8, R = C_5H_{11}, X = H
9, R = C_5H_{11}, X = Br

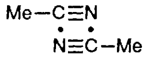


10, R = Me, X = Br
11, R = Me, X = CH_2Cl
12, R = Me, X = CH_2SH
13, R = CH_2CH_2Ph, X = Br
14, R = CH_2CH_2Ph, X = CH_2Cl
15, R = CH_2CH_2Ph, X = CH_2SH
16, R = C_5H_{11}, X = Br
17, R = C_5H_{11}, X = CH_2Cl
18, R = C_5H_{11}, X = CH_2SH

axes, four σ_v and one σ_h mirror planes (overall D_{4h} symmetry). The chemical shifts of the H_a and H_b carcerand signals are guest-sensitive, and their multiplicities indicate which rotations of the guest relative to the host are slow and which are fast on the ^1H NMR time scale. The chemical shifts of the guest hydrogens provide information about whether their protons are located in the strongly shielding 'temperate' or weakly shielding 'torrid' zones of the global hosts.

The spectrum of **3**·MeCOEt gave two kinds of H_a and H_b signals, indicating that the guests are rotating rapidly around the long polar axis of the host (coincident to the long guest axis), but not about the shorter equatorial axes. The spectrum of **3**·EtCOEt gives only one pattern of H_a and H_b signals. The EtCOEt guest is like-ended, and its long axis must be coincident with the long polar axes around which this guest must rotate rapidly. Since EtCOEt is a longer molecule than MeCOEt, rotation of the former about the host's shorter equatorial axes must also be slow or non-existent. The spectra of the other carceplexes each contain only one H_a and H_b pattern, suggesting that the guests are rotating rapidly on the ^1H NMR time scale around both the equatorial and polar axes. This interpretation is consistent with expectations based on molecular model examinations.

The guest-proton signals moved 1–4 ppm upfield from their normal positions. For example, the CH_3 signals' δ values were: **2**·2CH_3OH, −0.75; **2**·CH_3CN, −1.64; **2**·2CH_3CN, −2.16; **3**·CH_3CH_2OH, −1.18; **3**·$(CH_3)_2NCHO$, −0.10 and −0.33; **3**·$CH_3CH_2COCH_3$, −1.94 and −3.08; **3**·$CH_3CH_2COCH_2CH_3$, −3.39. The fact that the protons of **2**·2CH_3CN occur at higher field than **2**·CH_3CN suggests that the two methyl groups of the former are located in the temperate zones of the host in a dimeric structure **19**. The high



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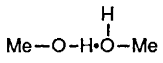

$\mathrm{Me{-}O{-}H{\cdot}\overset{H}{O}{-}Me}$

20

upfield shifts of the $2\mathrm{C}H_3\mathrm{OH}$ suggest these Me groups also occupy the temperate zones in a dimeric structure **20**, which places the hydrogen-bonded hydroxy groups in the torrid zone. In variable temperature ^{1}H NMR experiments, the O*H* signal moved monotonically from $\delta = -0.48$ at $-50\,°\mathrm{C}$, to -0.72 at $22\,°\mathrm{C}$, to -1.05 at $110\,°\mathrm{C}$. The relative lower field resonances of the OH proton at lower temperatures are consistent with increased association of the methanol molecules at lower temperatures.[5]

The first-order rate constants (k/min^{-1}) were measured for **2**·2MeCN → **2**·MeCN + MeCN at various temperatures (± 1 K) in $\mathrm{CDCl_2CDCl_2}$ by following the disappearance of the δ -2.15 signal for the **2**·$2\mathrm{C}H_3\mathrm{CN}$ carceplex and growth of the δ -1.64 signal for **2**·$\mathrm{C}H_3\mathrm{CN}$ for solutions of the initially obtained mixture of **2**·$2\mathrm{C}H_3\mathrm{CN}$ and **2**·$\mathrm{C}H_3\mathrm{CN}$ produced in the shell closure. Values obtained were as follows: at 383, 1.8; 373, 0.13; 363, 0.05; and at 353 K, 0.02 min^{-1}. A plot of log k *vs.* $1/T$ provided $E_a = 20$ kcal mol^{-1}‡ for the unimolecular decomplexation process. A sample of **2**·MeCN proved to be stable for five days when heated to 215 °C in 1,2,4-trichlorobenzene. We conclude from molecular model examination that **2**·2MeCN is somewhat strained, and that the expelled MeCN molecule escapes through the small portals between the four phenylethyl groups at the north and south polar regions. Possibly the expelled molecule is driven out by collisions between thermally excited pairs of the two prisoner molecules (a billiard-ball effect). Attempts failed to expel a molecule of MeOH from **2**·2MeOH by heating the substance dissolved in $\mathrm{C_2D_2Cl_4}$ at 110 °C for five days. Attempts failed to introduce a molecule of MeCN by refluxing the carceplex in 2 : 1 MeCN–$\mathrm{MeC_6H_5}$ for four days. Similar attempts failed to introduce $\mathrm{H_2O}$ into the same carceplex by heating it in a solution of 9 : 1 (v) $\mathrm{Me_2NCH{-}H_2O}$ at 100 °C for seven days.

These carceplexes in the solid state contain immobile hosts but confined mobile guests, not dissimilar in this respect to liquid crystals. We are examining these and other carceplexes for possible material science applications suggested by those of liquid crystals.

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References

1 D. J. Cram, S. Karbach, Y. H. Kim, L. Baczynskyj and G. W. Kalleymeyn, *J. Am. Chem. Soc.*, 1985, **107**, 2575; D. J. Cram, S. Karbach, Y. H. Kim, L. Baczynskyj, K. Marti, R. M. Sampson and G. W. Kalleymeyn, *J. Am. Chem. Soc.*, 1988, **110**, 2554.
2 J. C. Sherman and D. J. Cram, *J. Am. Chem. Soc.*, 1989, **111**, 4527.
3 L. M. Tunstad, J. A. Tucker, E. Dalcanale, J. Weiser, J. A. Bryant, J. C. Sherman, R. C. Helgeson, C. B. Knobler and D. J. Cram, *J. Org. Chem.*, 1989, **54**, 1305.
4 C. Beaugrand and G. Devant, *Adv. Mass Spectrom.*, 1980, **8B**, 1806.
5 J. W. Akitt, *NMR and Chemistry*, Chapman and Hall, New York, 1983, p. 99.

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‡ 1 cal = 4.184 J.