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[5] The methyl group in $(\equiv SiO)_2Ta-Me$ (**3**) necessarily comes from a reaction between monolabeled ethane and **2**. Since no isotopic effect was observed, the CH_3 group in **3** has equal probability of being labeled or unlabeled.

[6] In a batch reactor, secondary reactions between unlabeled and dilabeled ethanes and **3** can occur; the statistical 1:2:1 distribution of unlabeled, monolabeled, and dilabeled molecules is not affected by such a process. Consequently, the value calculated for the ratio of rates of degenerate/productive metathesis is underestimated.

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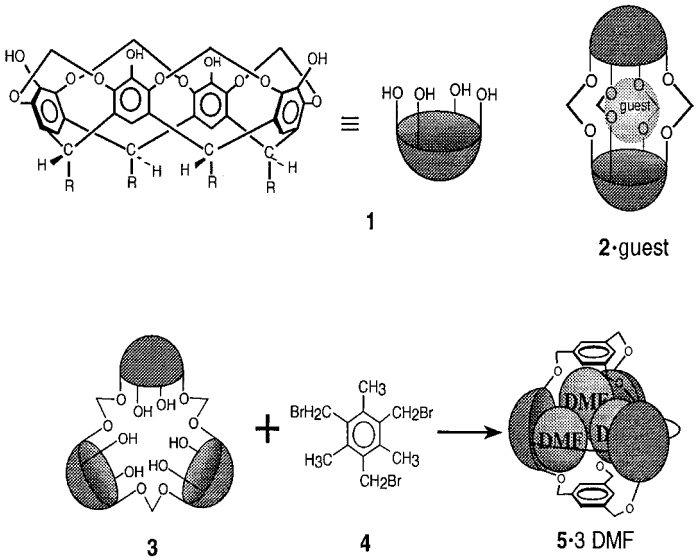
A Giant Carceplex Permanently Entraps Three Organic Molecules**

Naveen Chopra and John C. Sherman*

A current trend in supramolecular chemistry is the creation of large hosts that can accomodate several guests or one large guest. Particularly exciting is the possibility of encapsulating several molecules within molecular vessels and thus facilitating the study of a "microsolvent". The formation of such a species could allow a sophisticated study of templation versus solvent effects, as several molecules may have to be displaced by several others. To date, carceplexes, which permanently entrap molecules within their confines,[1] were only shown to entrap single small guest molecules.[2, 3] We report here the preparation of a carceplex roughly triple the size of any reported previously. We demonstrated the clean and selective permanent entrapment of three molecules of DMF and probed the properties of the entrapped microfluid medium. Such a system should provide a novel opportunity to study complex template effects.

Many large host systems have been reported[4] that could potentially be used to bind several guests: The holand by Reinhoudt et al. is a very large and rigid macrocycle of four concave host units.[3b] It has a huge cavity with correspondingly large holes; although it has not been shown to retain or complex guests, related species have been shown to bind steroids.[4f] The resorcinarene hexamer of Atwood and MacGillivray is a noncovalent assembly that may contain several solvent molecules according to electron density found in the crystal structure; no definitive characterization of encapsulated guests has been reported, nor has the assembly been shown to retain guests in solution.[5] Rebek and Conn encapsulated single large guests in their capsules, and in one case two guests were complexed; the reversible complex formation indicates rapid guest exchange.[6] Cram et al. reported several large hemicarceplexes, in which large portals allow guests to escape and preclude the retention of small molecules.[7] In contrast, the host reported here is unique in that it irreversibly retains several guest molecules.

In designing a large carceplex, certain criteria must be met, including structural rigidity and an effectively closed surface. Cavitands such as tetrol **1** (Scheme 1) are rigid bowl-shaped



Scheme 1. Schematic representation of the synthesis of carceplexes containing guest molecules. R = CH_2CH_2Ph. For clarity, methyl groups are omitted from the caps of **5**·3DMF.

molecules with an enforced cavity and are hence attractive building blocks for the construction of carceplexes. Indeed, two molecules of tetrol **1** were linked to create the small carceplex **2**.[3a] We recently reported the synthesis of a cyclic trimer of bowls (**3**),[8] which is a rigid barrel-shaped molecule with an enforced cavity. Trimer **3** seems ideally suited as a precursor for a large carceplex, and hence it was combined with cap **4** in DMF with K_2CO_3 as base in the presence of KI at ambient temperature for 24 h. The product was identified as carceplex complex **5**·3DMF (36% yield). The complex **5**·3DMF is readily soluble in $CHCl_3$ and was easily isolated from polymeric side products by chromatography on silica gel. The matrix-assisted laser desorption/ionization (MALDI) mass spectrum of **5**·3DMF showed a single predominant peak (m/z: 3641; calcd for **5**·3DMF·Na^+: 3642), which

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suggests that **5** selectively entraps three DMF molecules; peaks for two or four entrapped DMF molecules were not observed. No DMF was lost from **5**·3DMF on heating to 160 °C for 6 h in nitrobenzene. Figure 1 shows a space-filling drawing of **5**·3DMF; it is apparent that the vessel is effectively sealed.

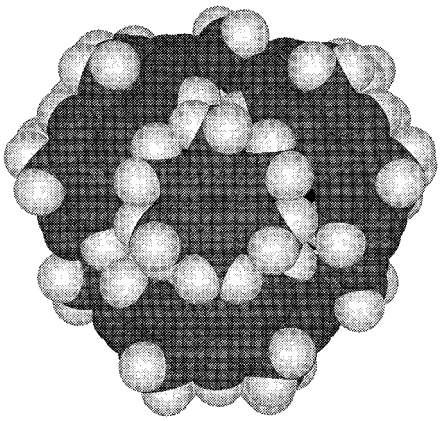

Figure 1. Space-filling depiction of **5**·3DMF. The view is downwards onto the top of a cap. The structure was drawn with Chem 3D Pro (Cambridge Software) and energy-minimized by MM2 calculations. Pendent phenethyl groups are omitted for clarity.

The ^{1}H NMR spectrum of **5**·3DMF in $CDCl_3$ is quite simple, and the signals for the entrapped DMF molecules are easily assigned (Figure 2). The integration is consistent with the composition of three DMF molecules per carceplex. The signals of the entrapped DMF molecules are shifted upfield from those of free DMF in solution; the degree of shielding varies significantly with the position of the guests in the interior of the carceplex and thus provides a "magnetic map" of guest orientation. The $\Delta\delta$ values in $CDCl_3$ at ambient temperature are 2.97 and 1.94 for the *N*-methyl groups (*syn* and *anti* assigned arbitrarily) and 2.08 for the formyl protons. These $\Delta\delta$ values are somewhat smaller than those of **2**·DMF,[3a] and this implies a more spaceous interior for **5**. Indeed, a CPK model of **5**·3DMF reveals that the DMF molecules have ample room to move around inside.

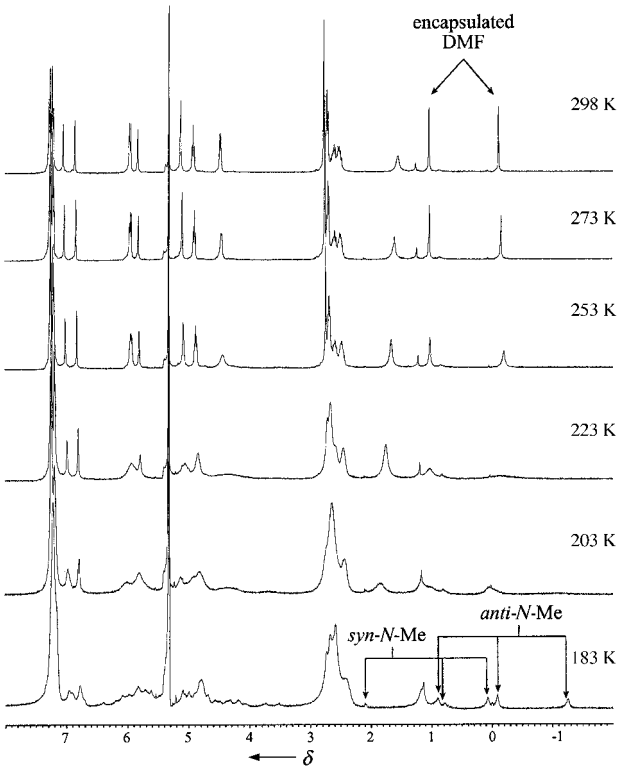

Figure 2. ^{1}H NMR (400 MHz) spectra of **5**·3DMF in CD_2Cl_2 (*syn*- and *anti*-*N*-methyl groups assigned arbitrarily).

Not surprisingly, there is only one set of ^{1}H NMR signals for the entrapped DMF molecules; this suggests that all three move rapidly within the carceplex on the ^{1}H NMR timescale. Variable-temperature ^{1}H NMR has been used to probe the mobility of guests entrapped in carceplexes.[3a, 9] For example, the energy barrier to rotation about amide bonds is sensitive to the phase and to solvent polarity in solution: The barrier generally decreases on going from a polar solvent to a nonpolar solvent to the gas phase.[10] In ^{1}H NMR spectra of **5**·3DMF in [D_5]nitrobenzene from 298 K to 423 K, the *N*-methyl signals broaden as the temperature is increased; at 423 K they were indistinguishable from the baseline. The coalescence temperature T_c was estimated to lie between 423 and 428 K, which corresponds to a $\Delta G^{\ddagger}$ value[3a, 9] of 19.3–19.5 kcal mol^{-1} for rotation about the C–N bond. This energy barrier is lower than that of free DMF in nitrobenzene (20.2 kcal mol^{-1}),[3a] but slightly higher than that of the single DMF molecule in **2**·DMF (18.9 kcal mol^{-1}).[3a] These data imply that the interior of **5**·3DMF resembles the gas phase less than that of the smaller carceplex or that it is more like a polar solvent. Since CPK models suggest that the three DMF molecules have much more freedom in **5**·3DMF than the single DMF molecule in **2**·DMF, it seems that the three DMF molecules create a polar "microsolvent" environment within the cavity of **5**.

Low-temperature ^{1}H NMR experiments in CD_2Cl_2 (Figure 2) showed that at 223 K the signals for *N*-methyl groups broadened out entirely into the baseline. At 183 K, new signals appeared: One set of *N*-methyl signals at $\delta = -1.2$, -0.1, and $+0.9$, which coalesce at $\delta = -0.1$, and another at $\delta = +0.1$, 0.8, and 2.1, which coalesce at $\delta = +1.0$. Hence, the three DMF molecules appear to reside in unique and dramatically different environments, for which the $\Delta\delta$ values relative to the *N*-methyl signals of free DMF range from 0.8 to 4.1.[11] The IR spectra show two carbonyl bands (1676 and 1682 cm^{-1}), and this suggests that at least one DMF molecule is in a different environment than the other two on the IR time scale. This may indeed be the same nonequivalence that is observed by ^{1}H NMR spectroscopy at low temperature, as it is likely that two of the three carbonyl bands are simply coincident (the bands at 1676 and 1682 cm^{-1} are themselves only just resolvable).

The entrapment of several molecules offers new opportunities to explore the chemical and physical properties of confined media. One of our interests in container compounds is the mechanism of their formation. In particular, what is the role of the guest molecule as a template in the assembly process? We studied this process in detail for a small

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carceplex with a single small molecule as template.[12] A current challenge is the exploration of larger containers, for which a large molecule or several small molecules can act as templates. Such a system would add the dimension of guest molecularity to the template question. Moreover, the effect of solvation would be far more complex because excluding solvent by simply using a large molecule would no longer be practical. We have demonstrated here the first step toward such a program, the creation of a large robust container that permanently entraps several molecules, the number, identity, "effective phase," mobility, and orientation of which have been clearly characterized. Efforts are currently underway to optimize the synthesis of **5** · guest complexes so as to analyze the role of templation.

Experimental Section

5 · 3 DMF: Trimer **3** (25.4 mg, 0.00823 mmol), K_2CO_3 (70 mg, 0.506 mmol, 61 equiv), KI (85 mg, 0.512, 62 equiv), and 1,3,5-(bromomethyl)mesitylene (20.5 mg, 0.0511 mmol, 6 equiv) were added to DMF (10 mL). The reaction mixture was stirred under N_2 for 24 h at 25 °C. The solvent was removed in vacuo, and HCl (2 M, 30 mL) was added to the crude mixture. The aqueous layer was extracted with $CHCl_3$ (3×10 mL), and the combined $CHCl_3$ extracts were dried with anhydrous $MgSO_4$, filtered, and evaporated to give a brown residue, which was eluted through a pad of silica gel with $CHCl_3$. A purple band indicating the presence of I_2 was coeluted with the desired product. This purple band was collected, solvent was removed and the residue was recrystallized from $CHCl_3$/hexanes to give 10.7 mg of **5** · 3 DMF as a white solid (0.00295 mmol, 36 %). M.p. > 250 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): $\delta = 7.10-7.30$ (br m, $CH_2CH_2C_6H_5$, $CHCl_3$), 6.99 (s, 6 H, *p*-H_{OAr}), 6.77 (s, 6 H, *p*-H_{acetal}), 5.97 (s, 3 H, $(CH_3)_2NCHO$), 5.96 (d, $J = 7.1$ Hz, 12 H, H_{out}), 5.85 (s, 6 H, H_{acetal}), 5.12 (s, 12 H, OCH_2Ar), 4.94 (t, $J = 7.7$ Hz, 12 H, $H_{methine}$), 4.47 (d, $J = 7.1$ Hz, 12 H, H_{in}), 2.77 (s, 18 H, $ArCH_3$), 2.71 (t, 24 H, $J = 7.6$ Hz, $CH_2CH_2C_6H_5$), 2.52 (m, 24 H, $CH_2CH_2C_6H_5$), 1.04 (s, 9 H, $(CH_3)_2NCHO$), −0.11 (s, 9 H, $(CH_3)_2NCHO$); IR (KBr): $\tilde{\nu} = 1682$, 1676 cm^{-1} ($\nu_{C=O}$); MS (MALDI): *m*/*z* (%): 3640 [*M*+Na$^+$] (100); calcd for $C_{219}H_{192}O_{36} \cdot 3\,C_3H_7ON + Na^+$: 3642; elemental analysis calcd for $C_{219}H_{192}O_{36} \cdot 3\,C_3H_7ON$: C 75.67, H 5.93, N 1.16; found: C 75.27, H 5.95, N 1.00.

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Porphomethenes and Porphodimethenes Synthesized by the Two- and Four-Electron Oxidation of the *meso*-Octaethylporphyrinogen**

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Porphomethene **B** and porphodimethene **C** are supposed to pave the way from porphyrinogen **A** to porphyrin (Scheme 1).[1, 2] However, these intermediates have never been synthesized from porphyrinogen but rather from metalloporphyrins by reductive protonation or reductive alkylation.[3] The yield and scale of such synthetic methods are severely limited due to the compulsory use of octaalkylmetalloporphyrins, whose steric bulk is necessary to protect the porphomethene and porphodimethene from the easy oxidation to porphyrins.[3] We report here on the stepwise deal-

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