# Communications to the Editor

Constrictive Binding of Large Guests by a Hemicarcerand Containing Four Portals[1]

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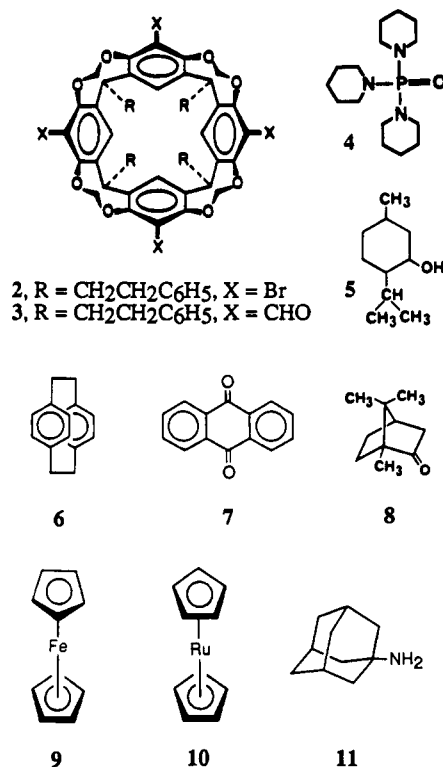
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We report here the simple synthesis[2] of hemicarcerand **1** and of 14 carceplexes composed of **1** containing guests of large enough dimensions to sterically inhibit dissociation and permit their isolation and characterization. We suggest the term "constrictive binding" for this phenomenon,[3] exemplified previously by the complexation of xenon by an empty hemicarcerand in $CDCl_3$.[4] The ^1H NMR spectrum of **1**[2] is consistent with the D_{4h} symmetry of the drawing of **1**, whose CPK model appears unstrained, and whose cavity is complementary to CPK models of [3.3]para-cyclophane or to 9,10-dimethoxyanthracene.
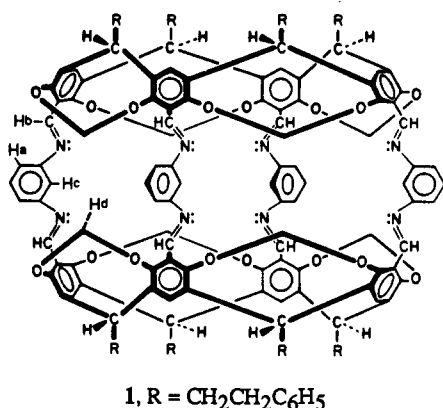
1, R = CH₂CH₂C₆H₅

Fourteen one-to-one hemicarceplexes were prepared by heating **1** to 80-120 °C in neat hexachlorobutadiene, triethyl phosphate, tripropyl phosphate, menthol (**5**), or hexamethylphosphoramide,

or by heating (90 °C) solutions of tripiperidylphosphine oxide (**4**) (too large for incarceration) containing [2.2]paracyclophane (**6**), anthraquinone (**7**), anthracene, camphor (**8**), ferrocene (**9**), ruthenocene (**10**), amantadine (**11**), hexamethylenetetramine, or adamantane.[6] All 14 hemicarceplexes formed were isolated and characterized by their ^1H NMR spectra and TLC R_f values.[7] All complexes except those of hexamethylphosphoramide, 1-anthracene, 1-anthraquinone, and 1-camphor were obtained pure and were fully characterized.[5]

2, R = CH₂CH₂C₆H₅, X = Br
3, R = CH₂CH₂C₆H₅, X = CHO

4

5

6   **7**   **8**

9   **10**   **11**

The guest's ^1H NMR signals were moved upfield upon complexation by as much as $\Delta\delta = 4.12$ ppm (for the 2,3-protons of anthraquinone) to as little as 0.42 ppm for those of 1-ruthenocene. Unlike the equatorial regions, the polar regions of the host's cavity are lined with shielding faces of aryl rings. Comparisons of the magnitudes of upfield shifts of various protons provided structural conclusions consistent with those based on CPK model examinations of many hemicarceplexes. Thus in 1-anthracene, 1-anthraquinone, 1-[2.2]paracyclophane, and 1-menthol, the protons terminating the long axes of the guests are much further upfield than those located toward the middle of the guest, indicating that the long axes of the host and guest in these complexes are roughly coincident. When N,N-dideuterioamantadine was substituted for amantadine in preparing 1-amantadine, the NH_2 signals at -1.40 ppm (2.78 ppm upfield of their nonincarcerated position) in the complex disappeared. We conclude that the NH_2 group is located in the polar cap of the complex. The inward-facing host protons H^c and H^d (see **1**) gave equally informative proton shifts reflecting guest characters and locations. For example, H^c moves upfield by 1.03 and H^d downfield by 0.09 ppm upon complexation with

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(2) (a) Tetrabromo cavitand **2** (Sherman, J. C.; Cram, D. J. *J. Am. Chem. Soc.* **1989**, *111*, 4527-4528) (21% from resorcinol, dihydrocinnamaldehyde, and CH_2BrCl, three steps) was metalated in THF with BuLi (-78 °C, 2 min), and *N*-formylmorpholine was added to give tetraaldehyde **3**, 75% (ref 5). A 2:1 molar ratio of 1,3-diaminobenzene to **3** in dry pyridine was stirred under argon at ~65 °C (4 days), the solvent was evaporated, and **1** was purified by chromatography (silica gel, R_f = 0.29, CH_2Cl_2, 45% yield, mp 240 °C dec). The sum of the elemental analyses (C, H, N, O) of dried **1** (ref 5) was 100.13%. The FAB MS of **1** gave the molecular ion (M + H⁺, 100%). All 500-MHz spectral protons of **1** except those of the eight pendant C_6H_5 groups were assigned by a homonuclear correlation COSY experiment (we thank Dr. Mike Gekel for help). NOE experiments (Derome, A. E. *Modern NMR Techniques for Chemistry Research*; Pergamon Press: Oxford, 1987; p 97) were performed on **1** in $CDCl_3$. Irradiation of H^a of **1** gave a -2% enhancement of H^b, whereas irradiation of H^b produced a -3% enhancement of H^a, but irradiation of H^c had no effect on H^a. Thus all eight configurations about the C=N bonds have H^b and the aryl syn to one another. (b) This paper is based on the Ph.D. Thesis of Dr. M. L. C. Quan: *Three New Classes of Hosts: Glycoside-Binding Hosts, Carcerands and Hemicarcerands*; University of California at Los Angeles, 1990, Chapter III, pp 93-171. Full documentation and discussion is found in this thesis, available to the public through University Microfilms International, 300 North Zeeb Road, Ann Arbor, MI 48106-1346.

(3) Derived from the Latin *constrictus*, meaning subject to compression, or to narrowing of a passage.

(4) Tanner, M. E.; Knobler, C. B.; Cram, D. J. *J. Am. Chem. Soc.* **1990**, *112*, 1659-1660.

(5) Elemental analyses were within 0.30% of theory, and MS or FAB MS gave the molecular ion.

(6) Under the latter conditions, [3.3]paracyclophane, 9,10-dimethoxyanthracene, 9,10-dimethylanthracene, dibenzenechromium, carboranes (1,7-$C_2B_{10}H_{12}$ and 1,10-$C_2B_8H_{10}$), and tetrabutyl phosphate failed to form complexes detectable by ^1H NMR.

(7) These values on silica gel (3% EtOAc in CH_2Cl_2) ranged from 0.16 (1-hexamethylphosphoramide) to 0.60 (1-ruthenocene).

[2.2]paracyclophane. Thus the equatorial H^c proton is shielded by the aryl faces of the guest, whereas the tropical H^d region of the host is slightly deshielded by the aryl edges of the guest.

The half-lives for guest liberation by 13 of the complexes were measured in $C_2D_2Cl_4$ and (or) $CDCl_3$ by following ^1H NMR signal changes with time, at temperatures of 25–134 °C. Values ranged from a low of 3.2 h at 25 °C for 1–hexachlorobutadiene in $CDCl_3$ to a high of 19.6 h for 1–ferrocene at 112 °C. The kinetic stability order was as follows: 1–ferrocene > 1–[2.2]paracyclophane > 1–adamantane > 1–ruthenocene > 1–amantadine > 1–hexa-methylenetetramine > 1–camphor > 1–anthraquinone ~ 1–tri-propyl phosphate > 1–anthracene > 1–menthol > 1–triethyl phosphate ~ 1–hexachlorobutadiene. Variable-temperature ^1H NMR kinetic measurements provided activation energies (E_a) for decomplexation of 19 ± 5 and 28 ± 2 kcal mol^{-1} for 1–adamantane and 1–ruthenocene, respectively. Notice that adamantane ($C_{10}H_{18}$), which is rigid and nearly spherical, is much more difficult to liberate than flexible tripropyl phosphate ($C_9H_{21}O_4P$).

We have exemplified hemicarceplexes stabilized by constrictive binding, and formable and dissociable by heating. The guests are as large as [2.2]paracyclophane. Similar complexes of drugs might find use as delivery systems.

Identification of Multiple Steps in the Dehydrogenation of Cyclic C$_6$ Hydrocarbons to Benzene on Pt(111)

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The dehydrogenation of cyclic hydrocarbons to benzene over transition-metal catalysts has been widely studied by ultrahigh vacuum surface science techniques as well as techniques applicable to supported metal catalysts.[1-10] However, only recently has cyclohexene been directly observed as a surface intermediate in the dehydrogenation of cyclohexane to benzene on Pt.[1] When the technique of laser-induced thermal desorption (LITD) combined with Fourier transform mass spectrometry (FTMS) was used, cyclohexene was observed in the reaction mixture. However, measurable quantities of the cyclohexene intermediate were observed only over a narrow range of surface coverages and temperatures, suggesting the existence of other stable surface intermediates. In an effort to further understand this prototypical hydrocarbon dehydrogenation reaction, we have extended our studies to several other C$_6$ hydrocarbons. The results, presented herein, indicate that although dehydrogenation of cyclohexane begins at ~180 K, benzene is not formed at a substantial rate until the surface reaches ~280 K. Therefore, another stable surface intermediate species must exist, and our results suggest that it has the stoichiometry C$_6$H$_9$.

In our experiments, a Pt(111) surface is initially held at low temperature (115 K) so that the reactant (e.g., cyclohexane) is molecularly adsorbed. LITD/FTMS experiments are performed
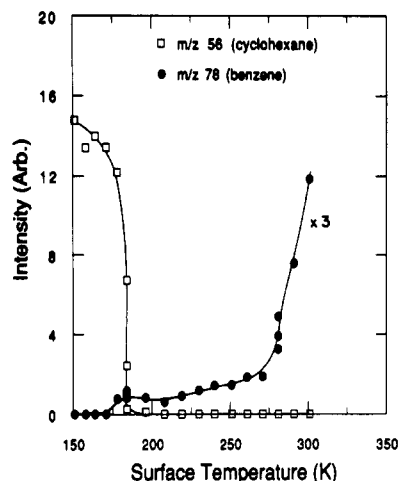

Figure 1. LITD/FTMS signals for cyclohexane (m/z 56 peak) and benzene (m/z 78 peak) as a function of the Pt(111) surface temperature following low-temperature adsorption of cyclohexane at low coverage (0.03 monolayer).

by focusing a pulsed laser beam (Lambda Physik excimer EMG103; 248 nm) down to a small spot (~0.002 cm^2) on the sample surface. This generates an extremely rapid temperature jump within the area of the small spot ($\Delta T \sim 1000$ K in 20 ns),[11-14] and molecular species on the surface are desorbed as intact neutrals. Even molecular adsorbates that decompose on the surface under slower sample heating conditions can be desorbed intact in this manner because of the extremely rapid heating rate of ~10^{10} K/s.[12] The desorbed intact neutral molecules are subsequently ionized by an electron beam and detected by FTMS.[15-18] For each laser pulse a complete mass spectrum is obtained of all the stable molecular species that were on the surface within the irradiated area. Effectively, analysis of the mass spectrum provides a snapshot of the surface species as the reaction progresses. The temperature dependence of a reaction can be followed by increasing the temperature of the Pt crystal in a stepwise manner and obtaining a mass spectrum of the reaction mixture from a new spot on the surface for each temperature step. In a typical experiment we hold the sample at a given temperature for ~30 s before obtaining the mass spectrum. The LITD/FTMS spectrum can be obtained and displayed in a period of ~1.5 s. If the spectrum has not changed from a previous one, we increase the sample temperature to the next step. If a change is observed in the spectrum (indicative of a surface reaction), we typically wait another time period and obtain another spectrum. The reaction is then followed in this manner until no further changes are observed in the spectrum. The sample is then heated to a higher temperature and the procedure repeated. Up to 50 spots can be interrogated without interference in a given experiment. The short time required to obtain and display the LITD/FTMS spectrum is very convenient for these reaction survey types of experiments. While stable molecular adsorbates are easily removed from the surface and identified in the manner just described, more strongly bonded adsorbate species, such as radical-like intermediates, may rearrange or decompose before desorbing.[19]

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