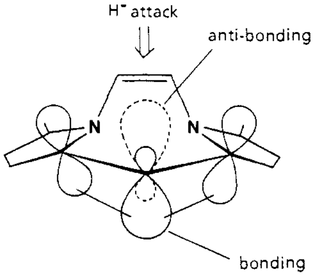

Figure 2. Exo-side attack of nucleophiles on **1**–**3** under the stereoelectronic control.

plane that contains four pyrrole nitrogens.[7] As the tilt of the pyrrole rings causes a greater overlap of the p-orbital of C(5) with that of C(4) or C(6) in the endo region than in the exo region, the anti-bonding π-orbital which interacts with nucleophiles should extend more to the exo side at C(5) (see Figure 2). This rationalizes the observed stereoselectivity, and a similar stereoelectronic effect should be expected for the NAD$^+$ model compounds[13] which are closely related to **1**–**5** in the sense that they are monocationic nitrogen heterocycles.

Finally, it should be emphasized that there are only a few examples of nucleophilic attack on the porphyrin system[2a,14] and that an N(21),N(22)-bridging group is removable in principle as has been demonstrated for the TPP analogue of **5**.[15] Thus, the present reaction is of importance not only as a new porphyrin redox system but also as a facile synthetic method for the meso-substitution of porphyrin by the use of ordinary carbanions.

Acknowledgment. This work was supported by a Grant-in-Aid for Scientific Research from the Ministry of Education, Science and Culture, Japan.

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(14) (a) Dolphin, D.; Muljian, Z.; Rousseau, K.; Borg, D. C.; Fajer, J.; Felton, R. H. *Ann. N. Y. Acad. Sci.* **1973**, *206*, 177. (b) Smith, K. M.; Barnett, G. H.; Evans, B.; Martynenko, Z. *J. Am. Chem. Soc.* **1979**, *101*, 5953. (c) Setsune, J.-i.; Yazawa, T.; Ogoshi, H.; Yoshida, Z.-I. *J. Chem. Soc., Perkin Trans. 1* **1980**, 1641.

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Cupped- and Cappedophanes, Two New General Classes of Compounds with Molecular Cavities

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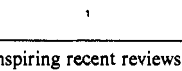
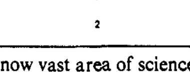
Received May 11, 1988

We describe here the first examples of two broad classes of molecules which should have potential as molecular hosts[1] and other novel structural features. Their structures are based on an *m*-terphenyl framework in which the outer rings are orthogonal to the central ring. Compounds of type **1** may have any set of atoms linking the 2,2″ and 6,6″ positions, thus forming a molecular bowl; as a consequence of the synthetic methodology, groups E other than hydrogen can also readily be incorporated, covalently bound to carbon 2′ in the middle of the bowl. Compounds of type **2**, which resemble a canopied gondola in shape, have a capping unit linked to the "outer" terphenyl rings.[2] If the connecting arms are long enough, these structures may include a passenger group E at position 2′.



1



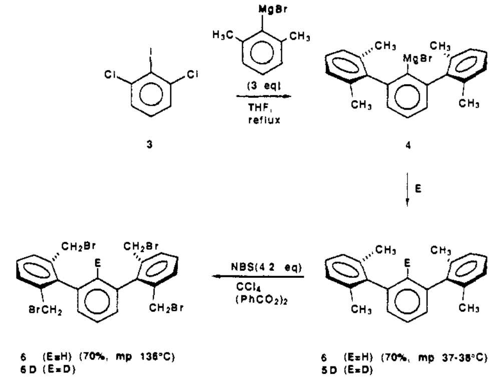
2

Because of their shapes and cyclophane[3] character, we refer to **1** and **2** as cupped- and cappedophanes, respectively. Several examples of each type, that can be synthesized in just a few steps, are described here.

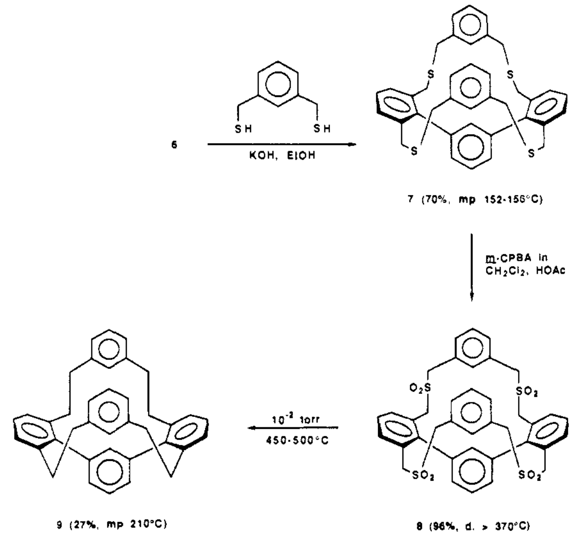
The key intermediate **6** for the cuppedophanes and cappedophanes reported here was prepared as shown in Scheme I. The conversion of **3** to **4** involves tandem aryne reactions recently developed in our group;[4] quenching allows the introduction of electrophiles (for example, deuterium) on the central ring at this stage.

Addition of a benzene solution of **6** and *m*-xylylenedithiol[5] (2 equiv) under high dilution techniques[6] to ethanolic KOH afforded tetrathia cuppedophane **7** in good yield. Oxidation gave the

Scheme I



Scheme II



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(1) For inspiring recent reviews of this now vast area of science, see: Lehn, J.-M. *Angew. Chem., Int. Ed. Engl.* **1985**, *27*, 90–112; "Molecular Inclusion and Molecular Recognition. Clathrates I", Weber, E., Ed. *Top. Curr. Chem.* **1987**, *140*. Rebek, J., Jr. *Science* (*Washington, D.C.*) **1987**, *235*, 1478–1484. Cram, D. J. *Angew. Chem., Int. Ed. Engl.* **1986**, *25*, 1039–1057. Lehn, J.-M. *Science* (*Washington, D.C.*) **1985**, *227*, 849–856. *Inclusion Compounds*; Atwood, J. L.; Davies, J. E. D.; MacNicol, D. D., Eds.; Academic Press: London, 1984; Vol. 2. Vögtle, F.; Müller, W. M. *J. Inclusion Phenom.* **1984**, *1*, 369–386. Gutsche, C. D. *Acc. Chem. Res.* **1983**, *16*, 161–170. For imaginative proposals for spheres, saucers, pots, collars, bowls, and other molecular cavities, see: Cram, D. J. *Science* (Washington, D.C.) *219*, 1177–1183.

(2) The examples described here have the "cap" linked to carbons 2,2″,6 and 6″ of the *m*-terphenyl unit, but other loci for attaching the "cap" should also be possible; the links between the "cap" and the *m*-terphenyl unit need not have identical lengths.

(3) For reviews, see: *"Cyclophanes"*, Keehn, P. M., Rosenfeld, S. M., Eds.; Academic Press: New York, 1983; Vols I and II. *"Cyclophanes I and II"*, Vögtle, F., Ed. *Top. Curr. Chem.* **1983**, *113* and *115*.

(4) Du, C.-J. F.; Hart, H.; Ng, K.-K. D. *J. Org. Chem.* **1986**, *51*, 3162–3165. Du, C.-J. F.; Hart, H. *J. Org. Chem.* **1987**, *52*, 4311–4314. Hart, H.; Ghosh, T. *Tetrahedron Lett.* **1988**, *29*, 881–884. Vinod, T. K.; Hart, H. *Tetrahedron Lett.* **1988**, *29*, 885–888.

(5) Autenrieth, W.; Beuttel, F. *Chem. Ber.* **1909**, *42*, 4357–4361.

(6) Vögtle, F. *Chem. Ind.* (*London*) **1973**, 1037–1038.

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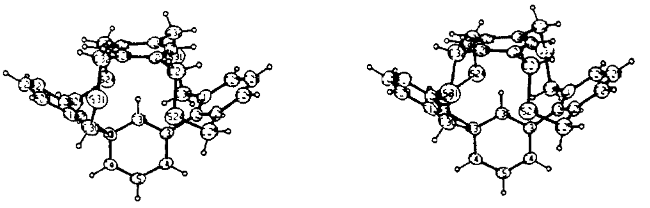
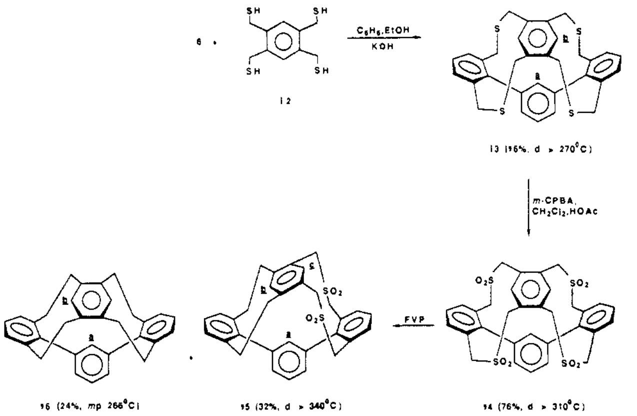


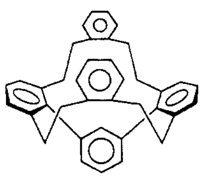
Figure 1. Stereoview of **13**.

Scheme III

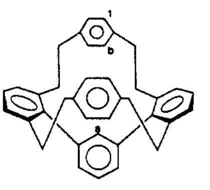


tetrasulfone **8** which, on flash vacuum pyrolysis,[7] gave hydrocarbon **9**[8] (Scheme II).

The structures of **9** and intermediates en route to it were clear from their ^{1}H NMR spectra.[9] The *o*- and *p*-analogues of **9** (i.e., **10** and **11**) were similarly prepared from *o*- and *p*-xylylenedithiols in comparable yields.[10]



10 (mp 198°C)



11 (mp 243°C)

A synthesis of four cappedophanes is outlined in Scheme III. Reaction of tetrabromide **6** with tetrathiol **12**[11] afforded **13**, plus an isomer not shown, in which the cap is turned 90° (1.9%). Oxidation of **13** with *m*-CPBA gave the tetrasulfone **14** which was pyrolyzed to a mixture of disulfone **15** and hydrocarbon **16**.[12]

Space-filling molecular models of these cappedophanes suggest that the structures are compact and somewhat strained. Indeed, one can only construct a CPK model of **13** if aromatic proton *a* is omitted from the model, and it is not possible to construct such models of **15** or **16**. The aromatic proton *a* in **13**, **15**, and **16** appears at δ 3.97, 3.31, and 3.77, respectively, highly shielded by the π cloud of the benzenoid cap. The canopy aromatic protons *b* are shielded by the outer rings of the *m*-terphenyl unit. They appear at δ 4.75 in **13**, at δ 3.67 in **16**, and as two singlets at δ 3.45 (b) and 5.16 (c) in the tilted canopy of **15**.[13]

An X-ray structure of **13** shows it to have only a C_2 axis, perpendicular to and through the center of the capping ring (Figure 1).[14]

We are actively extending our studies of cuppedophanes and cappedophanes in the many directions that suggest themselves, such as to polar and hydrogen-bonding linking chains, to nonproton E's, to other capping groups, and to frameworks other than *m*-terphenyl.[16]

Acknowledgment. We are indebted to the National Institutes of Health (GM 15997) for financial support of this research. We are indebted to Dr. Donald L. Ward for the X-ray structure and to Dr. Kurt Loening for assistance with nomenclature.

Supplementary Material Available: Physical data for all new compounds and crystallographic data for **13** (14 pages). Ordering information is given on any current masthead page.

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(7) Vögtle, F.; Rossa, L. *Angew. Chem., Int. Ed. Engl.* **1979**, *18*, 515–529.

(8) CAS name for **7**: 13*H*, 15*H*-1,19-(methanothiomethano[1,3]-benzenomethanothiomethano)-8,12:20,24-dimetheno-5*H*,7*H*-dibenzo[*k*,*r*]-[1,9]dithiacycloeicosin; for **9**: 5,6,12,13-tetrahydro-1,17-(ethano[1,3]-benzenoethano)-7,11:18,22-dimethenodibenzo[*a*,*h*]cyclooctadecene.

(9) For example, the proton at the center of the bowl in **9** on C2′ of the *m*-terphenyl unit appeared at δ 5.92 (absent in the deuterio analogue prepared from **6D**), shielded by the aryl rings; detailed descriptions and X-ray structures will be given in a full account.

(10) Models show **9** and **11** to be quite rigid, whereas **10** is fairly flexible; in accord, the NMR spectrum of **10** shows no exceptional high field aryl protons (δ 7.05–7.60, m, 18 H), whereas in **11** the proton at the bottom of the bowl (δ 6.59) as well as the "top" and "bottom" protons of the 1,4-linked benzene rings (δ 6.43, 6.27) were shielded, and the methylene protons were separated into four distinct four-proton sets (δ 2.53–2.61, 2.73–2.84, 3.05–3.14, and 3.26–3.38).

(11) Klieser, B.; Vögtle, F. *Angew. Chem., Int. Ed. Engl.* **1982**, *21*, 618–619.

(12) CAS name for **13**: 7,12-Dihydro-14*H*-1,9:10,18-bis(methanothiomethano)-19,23-metheno-5*H*-tribenzo[*c*,*h*,*o*][1,6]dithiacycloheptadecin; for **16**: 5,6,20,21-Tetrahydro-2,16:3,10-diethano-15,11-metheno-11*H*-tribenzo-[*a*,*e*,*i*]cyclopentadecene.

(13) Although the regioisomer of **13** with the canopy turned 90° with respect to the *m*-terphenyl unit also had a high field proton corresponding to proton a (δ 3.99), the canopy aromatic protons were deshielded (δ 8.30), thus allowing the structures of the two isomers to be readily distinguished.

(14) X-ray structures of selected cupped- and cappedophanes will be reported in due course in a full account. We note here, however, that the capping benzene ring in **13** deviates somewhat from planarity in a twist-boat conformation, that the sulfur-containing bridges occur in two different sets with substantially different dihedral angles, and that proton a is only 2.16 Å from the mean carbon plane of the capping ring.[15]

(15) For a recent study in which an sp^3-methine hydrogen is similarly poised with respect to a benzene ring, see: Pascal, R. A., Jr.; Grossman, R. B.; Van Engen, D. *J. Am. Chem. Soc.* **1987**, *109*, 6878–6880.

(16) Hart, H.; Harada, K.; Du, C.-J. F. *J. Org. Chem.* **1985**, *50*, 3104–3110. Harada, K.; Hart, H.; Du, C.-J. F. *J. Org. Chem.* **1985**, *50*, 5524–5528.

Molecular Recognition: Multipoint Contacts with New Sizes and Shapes

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We recently introduced new molecular shapes useful as probes for molecular recognition.[1] The structures are easily assembled from the condensation of Kemp's[2] triacid with suitable spacer groups. Their uniqueness derives from the unusual triaxial relationship that exists between the carboxyl functions; it provides an opportunity to engineer a U-turn into structures derived from it. As a consequence, the functional groups derived from the carboxylic acids tend to *converge* toward the center of the molecule. Here we describe the use of this architectural cliche with new spacer elements and multiple branch points.

Condensation of the acid chloride anhydride[2] **1a** with the 3-aminobenzyl alcohols **2** followed by oxidation[3] gave the aromatic aldehydes **3** (Scheme I). These were reacted at room temperatures with pyrrole under acid catalysis (CF_3CO_2H) to give the porphyrinogen, which was then oxidized with DDQ.[4] The re-

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(1) Rebek, J. Jr. *Science (Washington, D.C.)* **1987**, *235*, 1478–1484.

(2) Kemp, D. S.; Petrakis, K. S. *J. Org. Chem.* **1981**, *46*, 5140–5143. For an improved, large scale preparation, see: Rebek, J., Jr.; Askew, B.; Killoran, M.; Nemeth, D.; Lin, F.-T. *J. Am. Chem. Soc.* **1987**, 2426–2431.

(3) Corey, E. J.; Suggs, J. W. *Tetrahedron Lett.* **1975**, 2647–2650.