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Molecular Tweezers Based on Dioxa[2.2]orthocyclophane Skeleton

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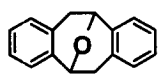
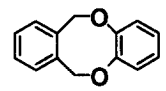
Abstract: Flexible molecular receptors having three aromatic chromophores can bind electron-deficient π-system such as TCNQ, PDA, TCNB with both face-to-face and face-to-edge interactions. A syn cofacial orientation of the two terminal aromatic rings is effective for binding the guest.

Recognition of planar molecules based on non-covalent interactions is of current interest in host-guest chemistry. Many structurally interesting hosts have been synthesized for the study of the nature of the binding interactions. Molecular tweezers, [1] containing two aromatic chromophores connected by spacer are suitable receptors for aromatic guests since they can hold the guest by the two aromatic arms with π-stacking interactions.[2] The perpendicular arrangement of two aromatic rings as was found in Kagan's ether **1**[3] is a good building block for constructing receptors[4] which bind aromatic guests with both face-to-face and face-to-edge interactions.[5]



1



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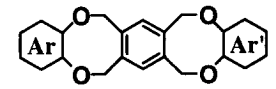

3 : Ar = Ar' = Benzene
4 : Ar = Benzene, Ar' = 9,10-phenanthrene
5 : Ar = 2,3-naphthalene, Ar' = 9,10-phenanthrene

In a previous paper,[6] we reported that dioxa[2.2]orthocyclophane (5,8-dihydro-1,4-dibenzo-[b,f]dioxocine) **2**[7] has a nearly perpendicular arrangement of the two benzene rings. The compounds (**3** - **5**) having two units of the dioxa[2.2]orthocyclophane within a molecule should thus be a good molecular receptor with tweezer-type arrangement of the two terminal aromatic rings since they are ca. 6.5 Å apart with face-to-face orientation when it has a syn conformation.

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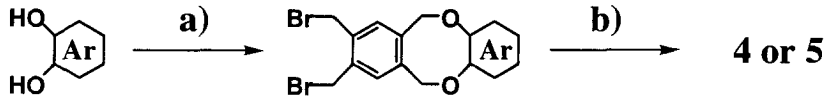
The molecular receptors **4** and **5** were synthesized by the successive coupling of 1,2,4,5-tetrakis(bromomethyl)benzene with the corresponding aromatic diols and 9,10-dihydroxyphenanthrene in the presence of Cs_2CO_3 in acetone (Scheme 1). Simple aromatics such as benzene and naphthalene showed no propensity for binding, while π-electron-deficient systems such as tetracyanoquinodimethane (TCNQ) **6**, pyromellitic dianhydride (PDA) **7**, and tetracyanobenzene (TCNB) **8** were complexed in solution; hence, electron donor-acceptor interaction plays an important role in the binding. New broad charge transfer bands were observed (for **5**; 520 (**6**), 520 (**7**), and 460 nm (**8**)). A 1:1 stoichiometry of the complex was determined by a continuous variation method using the CT-band in all cases. The host **3**[6] did not give any new charge transfer band nor any spectral change in its ^{1}H-NMR in spite of the addition of these π-electron deficient guests, suggesting the binding arms of **3** are not large enough for effective binding. By titrating a solution of a guest with the host using the complexation induced ^{1}H-NMR shifts of the guest, a standard hyperbolic curve could be constructed. The binding parameters (Table 1) were determined by direct fitting of this data using a nonlinear least squares fitting procedure.[8]

Table 1. Association constants (M^{-1})

Guest	4	5
6	35(3)	130(2)
7	60(7)	1000(90)
8	73(2)	1000(110)

Scheme 1



a) 1,2,4,5-tetrakis(bromomethyl)benzene, Cs_2CO_3, acetone, for **4** : Ar = benzene, 32%
for **5** : Ar = naphthalene, 28%

b) 9,10-dihydroxyphenanthrene, Cs_2CO_3, acetone, for **4** : Ar = benzene, 53%
for **5** : Ar = naphthalene, 37%

The structures of the host-guest complexes were examined by both ^{1}H-NMR and X-ray crystallography.[9] In all the complexes, guest aromatic protons are shifted upfield by more than 1.0 ppm (Table 2). The chemical shifts of the bound species are consistent with the structure in which the guests stack on the largest donor arm of the hosts. The crystal structure of these complexes confirms this binding mode. As expected, host **5** clearly has a molecular tweezer-type conformation with face-to-face *syn* arrangement of the two terminal aromatic rings (Figure 1). The two terminal chromophores lie parallel with each other as can be found from the angles between each terminal aromatic ring and the central durene ring of the complex **5•6** (naphthalene 91.6 °, phenenthrene 91.5 °). The distance between the least-squares plane

Table 2. Free and complexation induced chemical shifts of guests(ppm)

Guest	free	Δδ (4•Guest)	Δδ (5•Guest)
6	7.56	-1.34(6)	-1.64(2)
7	8.65	-1.10(4)	-1.31(3)
8	8.25	-1.07(2)	-1.35(6)

of the two aromatic arms is 6.54 Å. The guest is suitably positioned for stacking interactions with the naphthalene and phenanthrene chromophores and an edge-to-face interaction with the central durene bridge. The guest is parallel to each of the terminal aromatic chromophores. The distances between the least-squares plane of the two aromatic arms and the guest of **5•6** are 3.31 Å (from naphthalene) and 3.24 Å (from phenanthrene), respectively. Two hydrogens of **6** are pointed to the central durene ring at distances of 2.74 and 2.70 Å, suggesting favorable distances for attractive interactions between the partial positively charged hydrogens of the guest and the benzene ring of **5**.

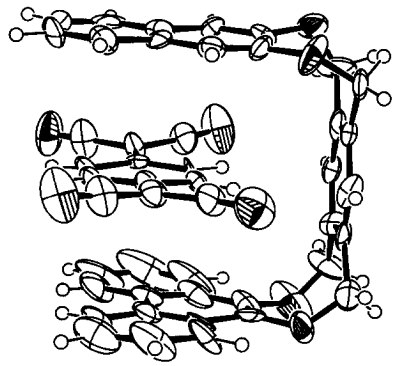
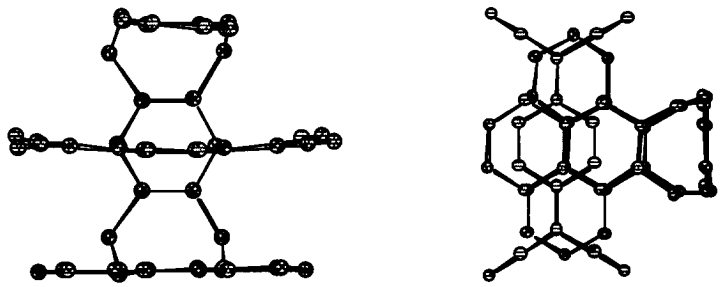


Figure 1. An ORTEP drawing of **5•6**.



(a) (b)

Figure 2. Front (a) and top (b) views of **5•6**

As can be seen, the 6-membered ring of the guest bent slightly to a boat form in the complex (Figure 2a). The complex has a roughly *Cs* symmetric structure and hence, the oxygen-carrying 6-membered ring of the naphthalene is superimposed on that of the phenanthrene ring with excellent overlap when viewed along the perpendicular direction of one of the two terminal arenes (Figure 2b). Unexpectedly, the conformer of host **4** in the crystal of the complex **4•6** is not tweezer form. It has L character-type conformation, in which the phenanthrene and central durene are perpendicular with each other. It forms a complex with **6** in a 2 : 1 fashion in crystal, in which two hosts hold the guest by face-to-face and face-to-edge interactions (Figure 3). While the two arenes (phenenthrene and durene) of **4** contribute significantly to hold the guest, the terminal benzene does not. This L character-type conformation may account for the weak binding of the guest in solution.

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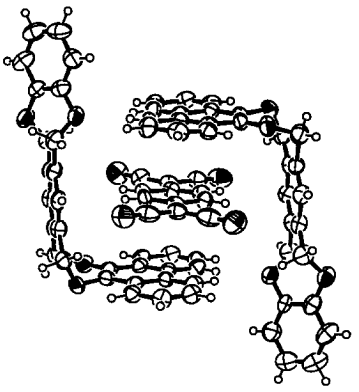

Figure 3. An ORTEP drawing of **4•6•4**.

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9) X-ray structural analysis of **4•6** and **5•6**: MXC-3 diffractometer,graphite monochromated MoKα, structure solved by direct method (SIR92), and refined with the full-matrix least-squares method against F^2 (SHELXL93). Complex $\mathbf{4_2•6•(acetone)_2}$: brown prisms, space group *P-1*, triclinic, a = 11.888(3), b = 11.919(3), c = 11.935(2) Å, α = 103.74 (2), β = 105.87 (2), γ = 108.67 (2)°, V = 1439.6(5) Å^3, 5135 measured, 4242 were observed (I > 2σ (I)). R = 0.049, wR^2 = 0.173; Complex **5•6**: brown prisms, space group $Pc2_1n$, orthorhombic, a = 17.212(2), b = 37.939(9), c = 15.462(3) Å, V = 10096(4) Å^3, 5339 measured, 3682 were observed (I > 2σ (I)). R = 0.054, wR^2 = 0.175; Crystallographic data (excluding structure factors) for the structure reported in this paper have been deposited with the Cambridge Crystallographic Data Center as supplementary publication.