▌Host–Guest Systems │*Hot Paper*│

From Packed "Sandwich" to "Russian Doll": Assembly by Charge-Transfer Interactions in Cucurbit[10]uril

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Abstract: As the host possessing the largest cavity in the cucurbit[*n*]uril (CB[*n*]) family, CB[10] has previously displayed unusual recognition and assembly properties with guests but much remains to be explored. Herein, we present the recognition properties of CB[10] toward a series of bipyridinium guests including the tetracationic cyclophane known as blue box along with electron-rich guests and detail the influence of encapsulation on the charge-transfer interactions between guests. For the mono-bipyridinium guest (methylviologen, MV^{2+}), CB[10] not only forms 1:1 and 1:2 inclusion complexes, but also enhances the charge-transfer interac- tions between methylviologen and dihydroxynaphthalene (**HN**) by mainly forming the 1:2:1 packed "sandwich" complex (CB[10]·2 MV^{2+}·**HN**). For guest **1** with two bipyridinium units, an interesting conformational switching from linear to "U" shape is observed by adding catechol to the solution of CB[10] and the guest. For the tetracationic cyclophane-blue box, CB[10] forms a stable 1:1 inclusion complex; the two bipyridinium units tilt inside the cavity of CB[10] according to the X-ray crystal structure. Finally, a supramolecular "Russian doll" was built up by threading a guest through the cavities of both blue box and CB[10].

Introduction

Simultaneous encapsulation of multiple components in a molecular container is an interesting topic because the reactivity and properties of molecules are often changed when they are trapped within well-defined nano-spaces.[1] Another attractive feature of multi-component assemblies is that ordered sequences and conformations can be controlled.[2] Among these multi-component assemblies, those that exhibit a "Russian doll" geometry are rare, but are particularly intriguing.[3]

Cucurbit[*n*]uril (CB[*n*], *n* = 5, 6, 7, 8, 10, 14) (Figure 1 a) is a family of macrocyclic hosts,[4] the supramolecular and host–guest chemistry of which has been developing rapidly. With a hydrophobic cavity and 2*n* carbonyl oxygen atoms on the portals, CB[*n*] show selective molecular recognition properties towards cationic and neutral guests. There are numerous review papers focusing on different aspects of the CB[*n*] chemistry (general introduction,[5] synthesis,[6] high affinity,[7]
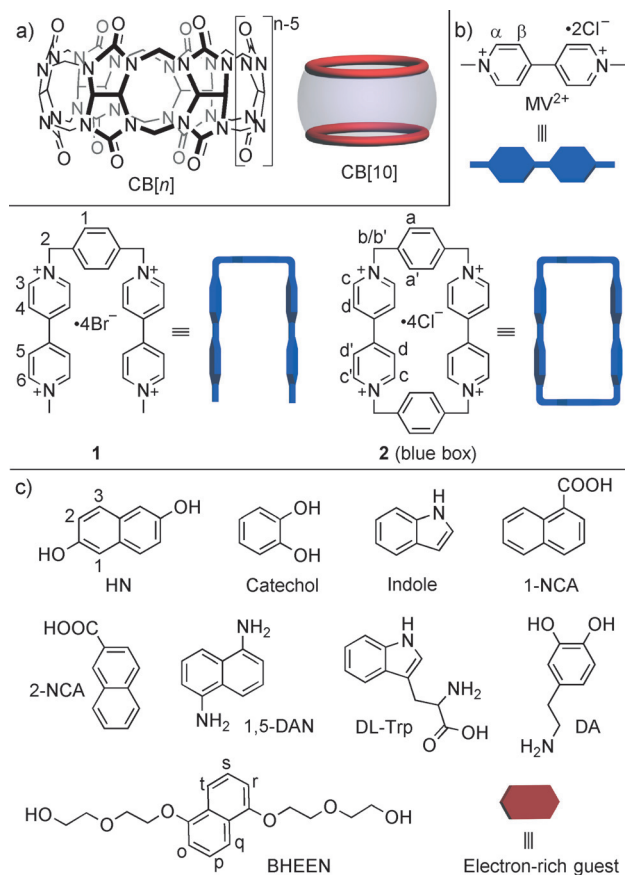

Figure 1. Structures of: a) CB host, b) bipyridinium guests, and c) electron-rich aromatic guests used in this study.

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🖳 *Supporting information and the ORCID identification number(s) for the author(s) of this article can be found under http://dx.doi.org/10.1002/chem.201604149.*

nanoreactor,[8] conformational control,[9] supramolecular polymer[10]). Most recently, Scherman published a comprehensive introduction of CB[n] (n = 5, 6, 7, 8) host–guest chemistry.[11] The development of methods for the synthesis of monofunctionalized CB,[12] broadens the scope of potential applications and enables workers in adjacent scientific fields to easily incorporate CB[n] hosts into their systems.

With the discovery of twisted CB[14] in 2013,[4d] CB[10] is no longer the CB with the largest number of glycoluril units. However, CB[10] possesses the D_{nh}-symmetry of the smaller CB[n] and displays the largest cavity among the CB[n] family with the portal diameter of 9.5–10.6 Å and volume of ~870 Å³.[13] This voluminous binding pocket endows it with unique molecular recognition and assembly properties, such as encapsulating calix[4]arene (including allosteric control),[13b] non-natural oligomers,[14] metalloporphyrin,[15] or anti-cancer drugs.[16]

Among the guests used in CB studies, methylviologen (MV^{2+}) has been established as a versatile probe to understand the connection between molecular recognition and redox properties due to its innate electrochemical properties by both the Kaifer and Kim groups. MV^{2+} forms a 1:1 inclusion complex with CB[7] and CB[8],[17] and interestingly a 1:2 complex (CB[8]·2$MV^{+\cdot}$) forms when MV^{2+} is chemically or electrochemically reduced to $MV^{+\cdot}$.[17c] Moreover, CB[8] forms a stable 1:1:1 ternary complex with MV^{2+} and 2,6-dihydroxynaphthalene (HN) featuring charge-transfer interactions between the electron-rich and electron-deficient molecule.[18] By taking advantage of this special recognition phenomenon, many groups made very interesting molecular machines and devices[19] as well as supramolecular polymers.[10b, 20]

Compared to the smaller CB[n] (n = 5, 6, 7, 8) homologues, the explorations of the recognition properties of CB[10] are still in the very early stages. Herein, we report the encapsulation/assembly of bipyridinium molecules (including MV^{2+}, a dibipyridinium guest and the tetracationic cyclophane known as blue box (Figure 1b)) and electron-rich compounds (Figure 1c) inside CB[10], and the influence of encapsulation on the charge-transfer interactions in the cavity of CB[10]. Finally we demonstrate that a "Russian doll" pseudorotaxane can be assembled by threading a guest through the cavities of both the blue box and CB[10].

Results and Discussion

Encapsulation of MV^{2+} and HN inside CB[10]

Unlike other CB[n] compounds that are slightly soluble in water, CB[10] is extremely insoluble in pure H_2O, but dissolution is often observed when it forms inclusion complexes with water-soluble guests. In some cases, the complex is also insoluble in aqueous solution. Encapsulation of MV^{2+} (chloride salt) inside CB[10] was established based on the observed solubilisation of CB[10] and was also verified by ¹H NMR titration experiments. The signals for α- and β-protons on the pyridinium units of MV^{2+} undergo significant upfield shifts ($\Delta\delta = 0.3$ and 0.5 ppm, respectively), whereas the CH_3 resonance remains constant (Figure 2 a,b). However, the binding between MV^{2+}
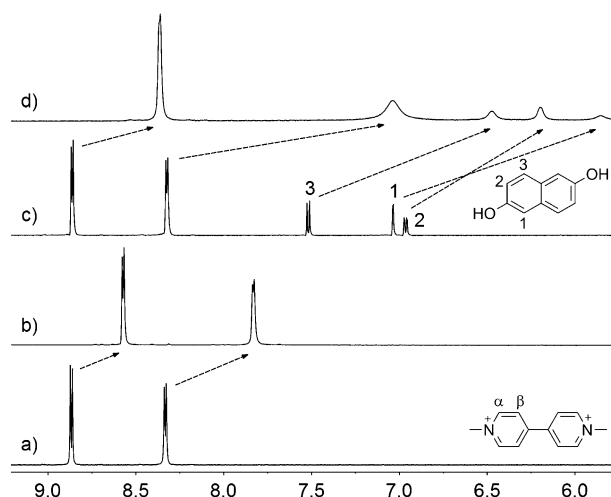
Figure 2. Partial ¹H NMR spectra (600 MHz, D_2O) of: a) free MV^{2+} (1.0 mM); b) MV^{2+} (1.0 mM) and excess solid CB[10]; c) a 2:1 mixture of MV^{2+} (1.0 mM) and HN; and d) a 2:1 mixture of MV^{2+} (1.0 mM) and HN, and excess CB[10].

and CB[10] exhibits fast exchange kinetics on a ¹H NMR timescale. Based on the integrals of the resonances in the ¹H NMR spectra shown in Figure 2b, we determined that the ratio between MV^{2+} and CB[10] is ~1:0.9, which implies the binding mode between MV^{2+} and CB[10] is probably 1:1.

As early as 2001, the Kim group reported that due to electrostatic repulsion CB[8] only binds one molecule of MV^{2+}, even though the cavity of CB[8] is big enough to encapsulate two MV^{2+} molecules.[17c] In contrast, we found CB[10] can accommodate two molecules of MV^{2+} and this was clearly observed by ESI-MS. As shown in Figure 3a, besides the ion at m/z: 923.3, which corresponds to the 1:1 complex ([CB[10] + $MV^{2+}]^{2+}$ = 923.3), ions at m/z: 508.2 and 689.6 were observed that correspond to the 1:2 complex ([CB[10] + 2$MV^{2+}]^{4+}$ = 508.2; [CB[10] + 2MV^{2+} + $Cl^-]^{3+}$ = 689.6). The formation of a 1:2 complex may be due to CB[10]'s large cavity, which minimizes electrostatic repulsion between the two MV^{2+} molecules. We are aware that ESI-MS results obtained in gas phase may not quantitatively reflect the situation in solution, but
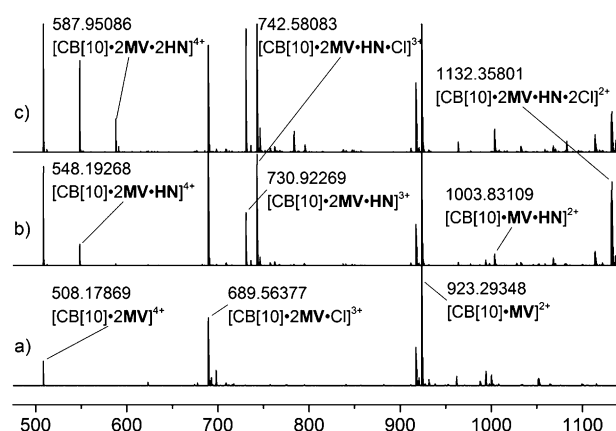
Figure 3. ESI-MS spectra of: a) MV^{2+} with excess CB[10]; b) a 2:1 mixture of MV^{2+} and HN, and excess CB[10]; and c) a 1:2 mixture of MV^{2+} and HN, and excess CB[10].

have found that ESI-MS is a very powerful tool in CB host–guest systems.[21]

As mentioned above, CB[8] forms a charge-transfer 1:1:1 ternary complex with MV^{2+} and 2,6-dihydroxynaphthalene (HN). In our case, we also observed that hetero-guest pairs bind into CB[10]. When a clear solution of MV^{2+} and HN was treated with solid CB[10], the solution immediately turned red. NMR titrations showed changes in the chemical shift of MV^{2+} and HN that are very similar to those observed upon addition of CB[8] (Figure 2 c,d).[18] When excess solid CB[10] was added to a solution of a 2:1 mixture of MV^{2+} (1.0 mM) and HN, we found the ratio between MV^{2+} and CB[10] is ~1:0.6 based on ^{1}H NMR integration. When 1:1 or 1:2 mixtures of MV^{2+} (1.0 mM) and HN were treated similarly, the ratio between MV^{2+} and CB[10] is 1:0.7–0.8. Although the binding process displays fast kinetics of exchange on the ^{1}H NMR timescale, these results imply that a 1:2:1 quaternary complex CB[10]·$2 MV^{2+}$·HN was the major complex. ESI-MS (Figure 3 b) clearly revealed the presence of the quaternary complex based on ions at m/z: 548.2, 730.9, 742.6, and 1132.4. In terms of the geometry of the charge-transfer complex, an alternating "packed sandwich" in which HN is in the middle and two MV^{2+} are on the sides is proposed (Scheme 1), similar to the alternating aromatic stacks found in Fujita's cage.[22] Although the 1:1:1 ternary complex was found (m/z peak at 1003.8), its intensity was quite low in the ESI-MS spectrum.

Interestingly, when a sample containing more HN (MV^{2+} and HN with a ratio of 1:2, and excess CB[10]) was examined by ESI-MS, we observed a 1:2:2 pentamolecular complex (m/z peak at 587.95) (Figure 3 c)! According to the charge-transfer interaction and MMFF calculation, we believe that in this complex two HN molecules are located between two MV^{2+} molecules (Scheme 1a). Although, we hypothesized that a 1:1:2 quaternary complex with composition CB[10]·MV^{2+}·$2 HN$ could also form, ESI-MS analysis did not support this expectation.

UV/Vis spectroscopy showed that in the presence of CB[10], the charge-transfer interaction between MV^{2+} and HN has been significantly enhanced, which is reflected in the increased charge-transfer absorption at ≈490 nm (Figure S1 in the Sup-

porting Information). As observed previously for CB[8],[18] the addition of CB[10] resulted in a large quenching of HN fluorescence in the presence of equimolar MV^{2+} (Figure S2 in the Supporting Information).

Inducing conformational change from linear to "U" shaped

Inspired by the formation of the 2:1 complex of MV^{2+} and CB[10], we wondered whether a covalently linked MV^{2+} dimer would bind to CB[10] with a "U"-shaped conformation? Accordingly, we synthesized compound 1 (bromide salt) by the methylation of the intermediate used in the synthesis of blue box (2).[23]

Unfortunately 1 itself did not form a "U" shape inside CB[10], even though the sample with a precise ratio of 1:1 was prepared. This guest did form a 1:2 complex with CB[10] in the presence of excess CB[10], as determined by the ^{1}H NMR integrals for peaks of guest and host (Figure 4 c) and ESI-MS. In the ESI-MS spectrum (Figure S3a and Table S1, Supporting Information), no ions were observed that could be ascribed to 2:2 complexes or supramolecular polymers. For comparison, we also tested the binding of guest 1 with CB[8]. ^{1}H NMR titration showed that 1 could also form 1:1 and 1:2 complexes with CB[8] (Figures S4 and S5, Supporting Information). In the 1:1 complex, CB[8] was located in the central region (e.g., phenyl ring) of the guest and the 1:1 binding exhibits slow exchange on the ^{1}H NMR timescale. The ^{1}H NMR spectrum of the 1:2 complex is very similar to the Figure 4 c. Interestingly, addition of catechol (1 equiv) to a solution of 1 and CB[10] (1:2) resulted in rapid formation of a precipitate. After the solid was removed by centrifugation, the solution had a pale-red color and the ratio of 1/CB[10] changed from 1:1.9 (Figure 4 c) to ≈1:1.1 (Figure 4 d) according to the ^{1}H NMR integration (peaks for catechol could not be found due to broadening). The signals for H_1 on the phenyl group and $H_{4/5}$ on the bipyridinium group underwent significant downfield and upfield shifts, respective-
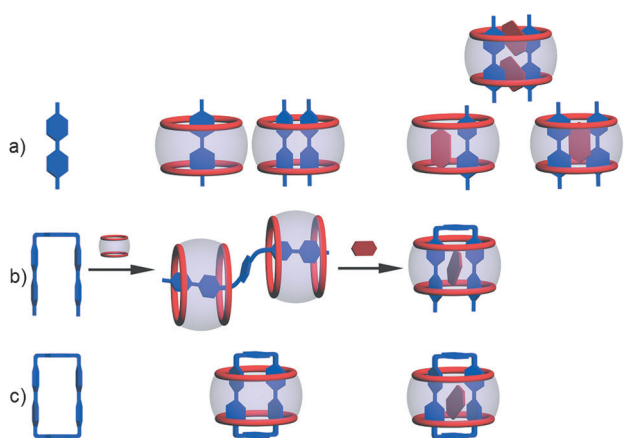
Scheme 1. Schematic illustration of the formation of an inclusion complex between guests and CB[10].
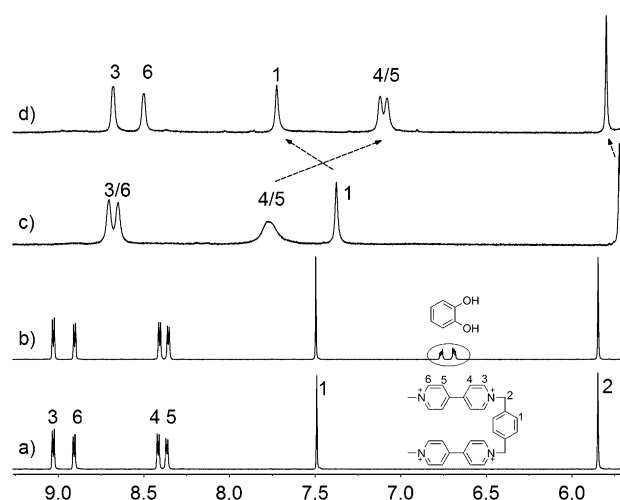

Figure 4. Partial ^{1}H NMR spectra (600 MHz, D$_2$O) of: a) free 1 (1.0 mM); b) a 1:1 mixture of 1 (1.0 mM) and catechol (resonance signals of catechol are circled); c) 1 (1.0 mM) and excess CB[10]; and d) 1 (1.0 mM) and excess CB[10] with addition of 1.0 equiv catechol (precipitate was observed).

ly. The ESI-MS spectrum (Figure S3b and Table S1, Supporting Information) provided strong evidence for the formation of a 1:1:1 ternary complex. In contrast, there were no obvious changes in chemical shift for a mixture of **1** and catechol (Figure 4a,b) in the absence of CB[10]. When **HN** was used instead of catechol, similar chemical shifts were observed but all peaks on **1** were broad, and precipitation occurred more slowly. Based on the combined inference of the above experiments, we are confident that the addition of catechol guest induced the linear shape of **1** to a "U"-shaped conformation (Scheme 1b) due to the enhancing charge-transfer interaction between **1** and catechol by CB[10]. Structurally related U-shaped complexes inside CB[8] have previously been observed by Kim and by us,[24] and external stimuli-responsive versions have been created by Schalley.[19b, 21]

Encapsulation of 2 within CB[10]

The formation of the 1:2 complex between CB[10] and **MV**$^{2+}$ also lead us to consider whether a smaller macrocyclic compound containing two bipyridinium groups would be encapsulated inside the cavity of CB[10]. Among these types of cyclic compounds, **2** (blue box) is a known building block pioneered by the Stoddart group to create mechanically interlocked molecular machines[25] based on its redox properties and its ability to bind to electron-rich aromatic compounds through charge-transfer interactions. Mixing CB[10] and **2** (chloride salt) resulted in the formation of the soluble CB[10]·**2** complex as established by ^{1}H NMR spectroscopy (Figure 5a–c). The 1:1 inclusion complex CB[10]·**2** exhibits slow kinetics of exchange on the ^{1}H NMR timescale. The complexation-induced changes in chemical shift allow us to conclude that the two bipyridinium moieties are located inside the cavity of CB[10], whereas the linking *p*-phenylene units are outside of the cavity of CB[10]. In theory, *p*-xylyenedication could compete with bipyridinium group for cavity inclusion (a quick test shows that *p*-xylyenediamine can make CB[10] soluble in H$_2$O), but this does not occur in practice. We think the main reason is that the bipyridinium group on **2** is too long to reside at the portal of CB[10], if the *p*-xylylene unit were located inside. Another reason is probably because the bipyridinium group binds to CB[10] stronger than *p*-xylyenedications. As an important control experiment, we verified that **2** is incapable of undergoing cavity inclusion within the less spacious cavity of CB[8].

To gauge the strength of the interaction between CB[10] and **2** we performed ^{1}H NMR competition experiments as described previously.[24a] For this purpose we added CB[5] (0.25 mм) to the aqueous solution of CB[10]·**2** (0.25 mм) and followed the composition of the mixture over time by ^{1}H NMR. Equilibrium was reached only after several days[24a, 26] and we used the known concentrations of the various species and the mass balance relationships to calculate a relative binding constant (K_{rel}) in the usual manner. The fact that the binding constant for tetracationic **2** is comparable to that of neutral CB[5] ($K_{rel} = 2.2$) was somewhat surprising and probably reflects the complementarity between the external surface of CB[5] and the internal surface of CB[10]. We performed dilution experi-
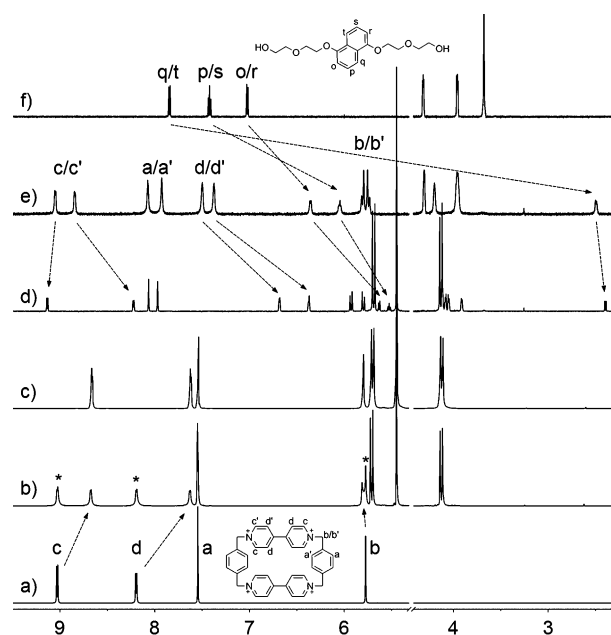

Figure 5. ^{1}H NMR spectra (600 MHz, D$_2$O) of: a) free **2** (1.0 mм); b) a 2:1 mixture of **2** and CB[10] (resonances of free **2** are marked with *); c) CB[10]·**2**; d) CB[10]·**2**·**BHEEN**; e) **2**·**BHEEN**; and f) free **BHEEN** (1.0 mм).

ments (1.0 mм to 10 μm CB[10]·**2**, Figure S6, Supporting Information) and did not observe any signals that could be assigned to free guest **2**. Assuming that we could detect 5% free **2** allows us to place a lower limit on K_a for CB[10]·**2** as $> 10^7$ m^{-1}.[27] We also compared the change in photophysical and electrochemical characteristics between free and bound **2**. Adding one equivalent of CB[10] to a solution of **2** leads to a dramatic decrease in the current levels in the cyclic voltammogram. Our interpretation is that encapsulation of **2** inside CB[10] reduced the diffusion coefficient of the complex (Figures S7 and S8 in the Supporting Information). In contrast, for CB[7]·**MV**$^{2+}$, the current level continuously decreased even when the amount of CB[7] added increased to three equivalents.[16b, 17a] For CB[8]·**MV**$^{2+}$, due to the formation of CB[8]·2**MV**$^{+\cdot}$, two additional redox waves appeared when the amount of CB[8] was added to 0.25 equivalents.[17b]

X-ray crystal structure of CB[10]·2

Luckily, single crystals of CB[10]·**2** that were suitable for structure determination were obtained from aqueous solution assisted by the addition of a small amount of KI.[28] In agreement with the conclusions based on the ^{1}H NMR data, the crystal structure directly shows that the bipyridinium units of **2** were located inside the cavity of CB[10] but are tilted with respect to the potential 10-fold symmetry axis (Figure 6). The dihedral angle between the mean plane of **2** and the equatorial plane of CB[10] is ~59.6°, which is very similar to the dihedral angle observed for CB[10]·CB[5] (~62.7°).[13a] The stability of the CB[10]·**2** complex can be attributed to the ion-dipole interactions between C=O···N$^+$ (the shortest distance between portal O on CB[10] and N on **2** is 2.93 Å), the presence of multiple
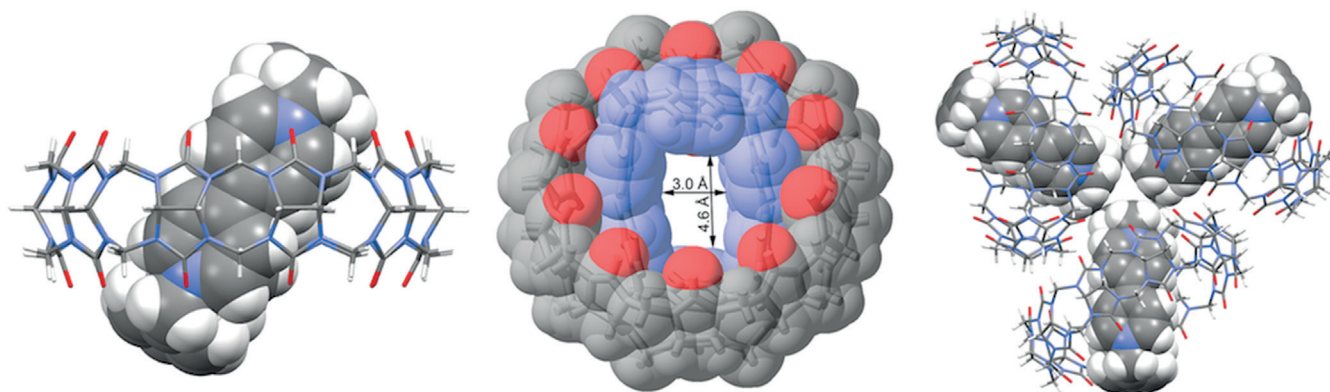
Figure 6. X-ray crystal structure of the inclusion complex CB[10]·**2** (left: side view; middle: channel view; right: packing view).

C=O···H—C close contacts (the shortest distance between portal C=O on CB[10] and C—H on **2** is ~2.27 Å), and of course the hydrophobic effect. Figure 6b nicely illustrates that, even though **2** is encapsulated by CB[10], there is still a rectangular channel through the two molecules of approximate 3.0×4.6 Å dimensions. Interestingly in the packing structure, the heads of three guests are very close to each other and the angle between them is almost 120° (accurately 119.86°). Moreover, the triangular structure of three CB[10], which was stabilized by multiple C=O···H—C close contacts (the shortest distance between portal O on CB[10] and H—C on the adjacent CB[10] is ~2.33 Å) is quite similar to that of reported free CB[10].[6a] It seems that inclusion of **2** inside CB[10] does not significantly perturb the packing preferences of CB[10] in the solid state (more packing views can be found in Figure S9 in the Supporting Information).

Binding of electron-rich aromatics inside 2 or CB[10]·2

Blue box **2** is a known host for various molecules containing electron-rich aromatic groups.[29] Previously, we have shown that **2** can form an encapsulation complex with *ns*-CB[10],[30] but we never checked the binding ability of **2** within the *ns*-CB[10]·**2** complex because we thought the two "inverted" CH$_2$ bridges in the middle of *ns*-CB[10] would occupy the cavity of **2**. As described above, the CB[10]·**2** complex exhibits a sizable rectangular channel through two hosts. Along with the importance of the synergistic effect in the molecular recognition of CB,[13b,31] we were interested to explore the synergistic effect involved when a host binds inside another larger host. Several aromatic guest molecules containing benzene or naphthalene rings with different substituents were selected for the study (Figure 1 c).

Similar to a previous study,[29] a visible absorption band arises when a solution of either **2** or CB[10]·**2** was titrated with a guest, due to charge-transfer interactions. Figure 7 shows the charge-transfer absorption band that appeared when adding 1,5-DAN to a solution of CB[10]·**2**. The equilibrium binding constants can be determined by fitting the change in absorbance of CB[10]·**2** as a function of [guest]. The K_a values of **2** or CB[10]·**2** towards guests are given in Table 1. In the
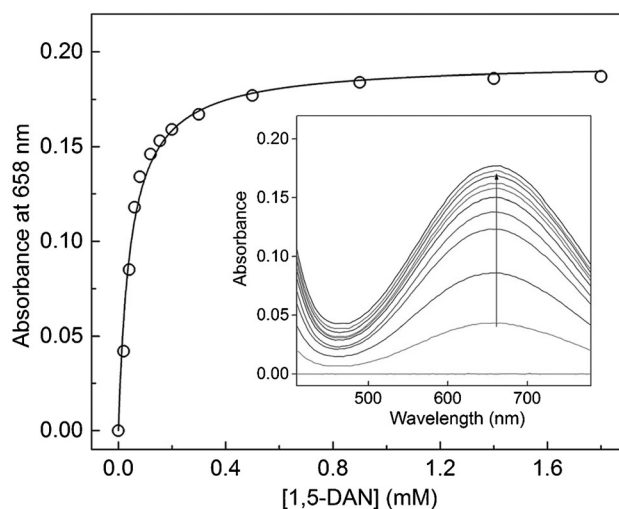

Figure 7. Plot of the absorbance at 658 nm as a function of 1,5-DAN concentration, the solid line is the curve fitting of the experimental data to the 1:1 binding model, $K_a = 2.3 \times 10^4 \, \text{M}^{-1}$ (insert: UV/Vis spectra recorded during the titration of CB[10]·**2** (0.1 mM) with 1,5-DAN (0-1.8 mM) in Tris-HCl buffer (50 mM, pH 7.0), showing the charge-transfer band at $\lambda_{\text{max}} = 658$ nm).

case of small guest catechol, its binding constant is five-fold higher with CB[10]·**2** than with **2**, probably because CB[10] provides secondary binding interactions that increase the hydrophobic effect for catechol. When indole is used, a slight increase in K_a of 36% is observed. Similarly, when moderate-sized guests like 1-NCA and 2-NCA are used, the binding constants toward **2** or CB[10]·**2** are comparable. We know CB[n] likes to bind to cationic species through the ion-dipole interactions, so we thought the binding constant would increase if an amino compound was used as a guest. Disappointingly, when di-amino compound 1,5-DAN was used as the guest, the binding constant of 1,5-DAN toward CB[10]·**2** was only slightly higher than that with **2**. We hypothesize that **2** has already satisfied the electrostatically negative portals of CB[10] such that the 1,5-DAN does not engender additional ion-dipole interactions with CB[10] in the CB[10]·**2**·1,5-DAN complex. When bigger and longer guests like DL-Trp and DA are used, the binding constant decrease in the presence of CB[10] might be

Table 1. Values of K_a [M^{-1}] measured for the interaction of electron-rich aromatic guests with **2**/CB[10]·**2** in Tris-HCl buffer (50 mM, pH 7.0) at 25 °C.

Guest	**2** [M^{-1}] (λ_{max} [nm])	CB[10]·**2** [M^{-1}] (λ_{max} [nm])
catechol[a]	$(2.1 \pm 0.1) \times 10^3$ (448)	$(1.0 \pm 0.1) \times 10^4$ (455)
indole[a]	$(1.4 \pm 0.1) \times 10^4$ (468)	$(1.9 \pm 0.2) \times 10^4$ (416)
1-NCA[a]	$(1.5 \pm 0.1) \times 10^4$ (423)	$(1.8 \pm 0.1) \times 10^4$ (438)
2-NCA[a]	$(9.8 \pm 1.1) \times 10^3$ (409)	$(1.0 \pm 0.1) \times 10^4$ (409)
1,5-DAN[a]	$(1.4 \pm 0.1) \times 10^4$ (686)	$(2.3 \pm 0.3) \times 10^4$ (658)
DL-Trp[b]	$(8.7 \pm 0.2) \times 10^2$ (412)	$(4.3 \pm 0.2) \times 10^2$ (401)
DA[b]	$1.1 \times 10^{3[c]}$	$(1.7 \pm 0.2) \times 10^2$ (487)

[a] Determined by adding the concentrated guest solution in DMSO. [b] Determined by adding the aqueous guest solution. [c] From ref. [29].

due to steric hindrance caused by a mismatch between the geometrical preferences of the **2**·guest and CB[10]·**2**·guest complexes (curve fitting for the UV/Vis titration was shown in Figure S10, Supporting Information). Based on the above results, we conclude that encapsulation of **2** inside CB[10] does not influence its recognition properties significantly. The reasons are probably because the binding is dynamic and the encapsulation of compound **2** in CB[10] did not change the relatively rigid structure of **2**.

"Russian doll" assembly

The first "Russian doll"-like assembly based on CB was reported by the Kim group.[3a] Threading a long-chain guest through both hosts comprising the CB[10]·**2** complex would allow us to prepare a new example of the type of intriguing supramolecular architecture. For this purpose, we selected **BHEEN** (1,5-bis[2-(2-hydroxyethoxy)ethoxy]naphthalene), which is an ideal guest because it forms a pseudorotaxane with **2** with a high $K_a \sim 1.5 \times 10^6$ M^{-1} in aqueous solution, driven by charge-transfer interactions and the hydrophobic effect.[32] In Figure 5 e, observation of two sets of host signals is due to the time-averaged C_{2h} symmetry of the complex **2**·**BHEEN** and the slow exchange on the NMR timescale, which is in agreement with previous results.[33] When CB[10] was added to the solution of **2**·**BHEEN**, as shown in Figure 5 d, dramatic upfield shifts of the H$_{2/6}$, H$_{3/7}$, and H$_{4/8}$ protons on the naphthalene unit and H$_{d/d'}$,H$_{c'}$ on bipyridinium units indicate that both **BHEEN** and **2** are encapsulated by CB[10] to form the "Russian doll" assembly CB[10]·**2**·**BHEEN**. Molecular modeling shows that **BHEEN** does thread through the cavity of two hosts (Figure 8). To our surprise, however, both NMR data (compare Figure 5 e with d, H$_c$ on bipyridinium unit slight shifts downfield) and modeling (dihedral angle between the planes of **2** and CB[10] is ~68.3°, compared to ~59.6° in the CB[10]·**2**) show that **2** in this complex prefers to close the portal entrance of CB[10], instead of decreasing the dihedral angle for the guest threading.

Conclusion

We have presented the binding of CB[10] with bipyridinium-containing guests. With mono-bipyridinium (methylviologen)
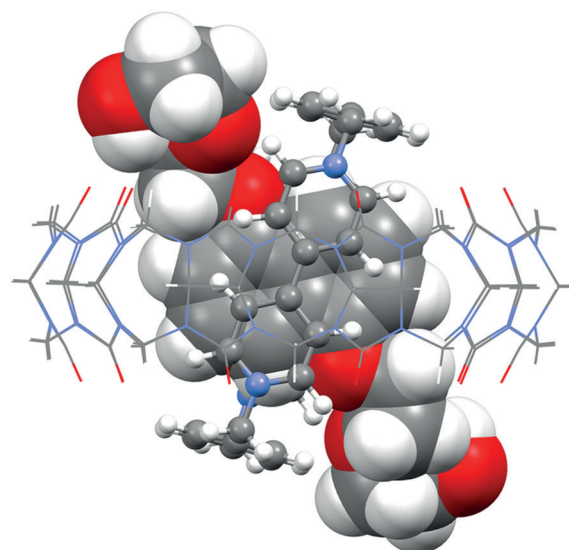

Figure 8. Modeling of CB[10]·**2**·**BHEEN** (MMFF).

as the guest, CB[10] not only forms 1:1 and 1:2 inclusion complexes, but also enhances the charge-transfer interactions between **MV**$^{2+}$ and **HN** by forming a 1:2:1 "sandwich" complex. When bis(bipyridinium) compound **1** was used as the guest we observed an interesting conformational switching from linear to "U"-shaped upon addition of catechol to a solution of CB[10] and **1**. We found that the tetracationic cyclophane blue box forms a stable 1:1 inclusion complex with CB[10]. Interestingly, two bipyridinium units tilt inside the cavity of CB[10] according to the X-ray crystal structure. The encapsulation of the blue box does not significantly affect its host–guest recognition properties.

Compared to other CB[n]s (n = 5, 6, 7), the larger cavity of CB[8] is more useful in the fabrication of supramolecular polymers[10] or as a nano-reactor.[8] The capacity of CB[10] for the simultaneous encapsulation of multiple guests makes it attractive as a building block to create 3D multi-functional supramolecular materials or to promote multi-component reactions. Furthermore, encapsulation of a host in a bigger host and the assembly of a "Russian doll" expand the use of CB[10] as a fascinating new building block to create new molecular machines and devices.

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[27] K_a calculation: since no obviously free guest signals were observed by diluting 1.0 mM CB[10]·**2** down to 0.01 mM, we assume that in the solution the amount of free guest was less than 5%. A K_a larger than 10^7 M^{-1} can be obtained by calculation.

[28] Crystal data for $(C_{60}H_{60}N_{40}O_{20})\cdot(C_{36}H_{32}N_4)I_4\cdot58\,H_2O$: $M_r = 3734.65$; rhombohedral; space group: $R-3c$; $a = 26.654(6)$, $b = 26.654(6)$, $c = 118.53(3)$ Å; $\alpha = \beta = 90$, $\gamma = 120°$; $Z = 18$; $V = 72930(40)$ Å^3; $\rho_{calcd} = 1.531$ g cm^{-3}; $\mu = 0.877$ mm^{-1}; $\theta_{max} = 16.50°$; $F(000) = 34704$ e; reflections collected/unique, 57285/4338 ($R_{int} = 0.1403$); final R indices $[I > 2\sigma(I)]$ $R_1 = 0.1504$, R indices (all data) $wR_2 = 0.3434$; GOF = 1.470 for all data. CCDC-1434842 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre.

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