A Self-Assembled Homooxacalix[3]arene-based Dimeric Capsule Constructed by a Pd^{II}−Pyridine Interaction Which Shows a Novel Chiral Twisting Motion in Response to Guest Inclusion

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Abstract: A capsule-like molecule was constructed by dimerization of pyridine-containing homooxacalix[3]-aryl esters utilizing a Pd^{II}−pyridine interaction when Li^+ ions were bound to the ionophoric lower rims. ^1H NMR spectral studies showed that the self-assembled molecular capsule **3b**·$(Li^+)_2$ has a highly symmetrical D_{3h}-structure. It was also found that this self-assembled molecular system can form capsular structures in the presence of Na^+ or ammonium (RNH_3^+) ions. Very interestingly, these molecular capsules are twisted into triply bridged helical structures, and chiral $R^*NH_3^+$ guests included in the cavity induce a change in the (*P*) versus (*M*) ratio, resulting in high chiral induction (∼70%). These results indicate that the self-assembled molecular capsule **3b** has a novel chiral factor in which the (*P*) versus (*M*) equilibrium is readily controllable by the inclusion of chiral guest molecules.

Introduction

Host−guest chemistry of half-bowl-shaped calixarenes and their analogues has been a central concern in the field of molecular recognition for a few decades.[1−7] A common characteristic of these hosts is the presence of a well-delineated "cavity" within the molecular structure, by which molecular recognition is achieved through size selectivity. Recent studies established that calix[*n*]arenes bearing "adhesive" functional groups on the upper rim can dimerize into a molecular capsule with large association constants for specific guest molecules.[5−7] Here, it occurred to us that the utilization of a coordination bond has escaped attention, for Fujita et al.[8] and Stang et al.[9] have shown a number of attractive examples of the coordination bond being very useful for the construction of self-assembled supramolecular structures.[10] We previously found that two homooxacalix[3]arenes (**1a**) dimerize with three $Pd^{II}(Ph_2PCH_2CH_2CH_2PPh_2)$·$(OTf^-)_2$ (**2a**) into a molecular capsule **3a**.[11,12] Spectroscopic studies have shown that **3a** can specifically include [60]fullerene, the selectivity of [60]fullerene versus [70]fullerene being nearly "perfect".[12,13]

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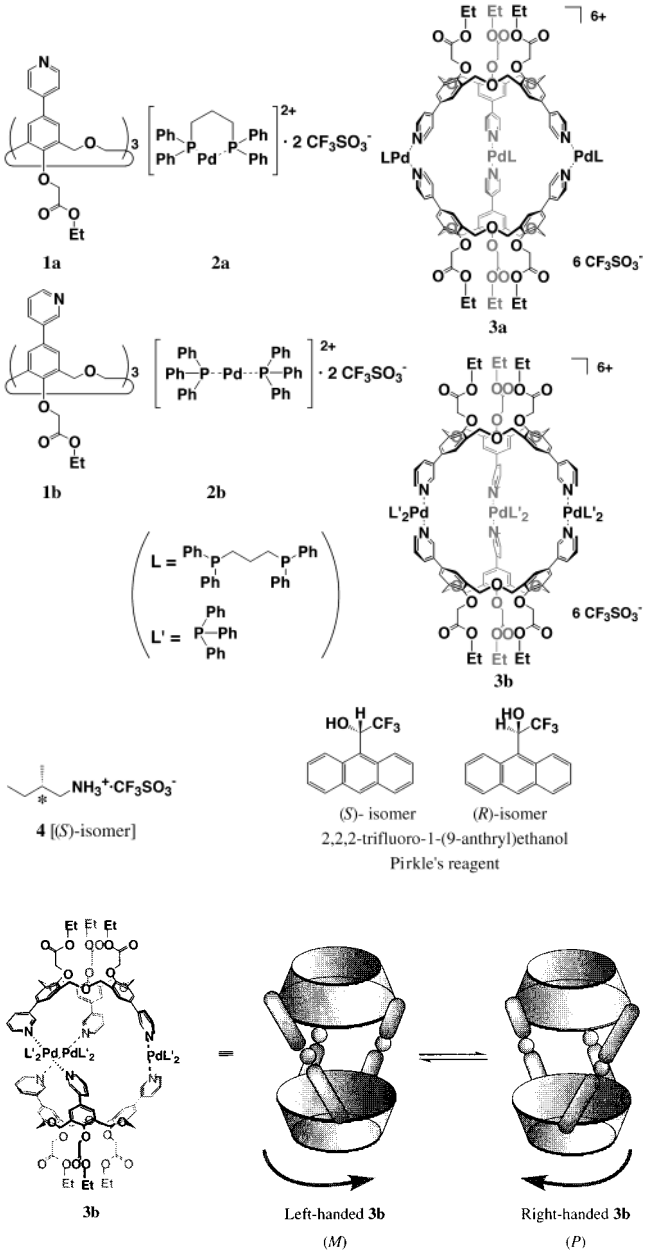
The purpose of the present study is to introduce a "chiral" factor into this class of calixarene-based molecular capsules. There are a few precedents in which "chiral" factors are introduced via covalent-bonds into molecular capsules.[14] To the best of our knowledge, however, there are few studies on chiral molecular capsules, which are constructed in a self-assembled manner. The design of such chiral molecular capsules is more difficult, but they should show more important and more interesting recognition properties from the viewpoints of practical applications and combinatorial chemistry.[15,16] We thus designed molecular capsule **3b**, which is composed of two homooxacalix[3]arene (**1b**) with 3-pyridyl substituents at the para-positions and three Pd^{II} complexes (**2b**). According to computational studies and examination of CPK molecular models, this capsule should be "chirally" twisted into either a right-handed (*P*) or a left-handed (*M*) form because of the asymmetrical structural characteristic of the 3-pyridyl substituents, and the ratio should be controlled by "chiral" guest molecules included in the cavity.[16] We here report novel findings that this molecular capsule has a chiral factor and the (*P*) versus (*M*) equilibrium is readily controlled by the inclusion of chiral guest molecules.



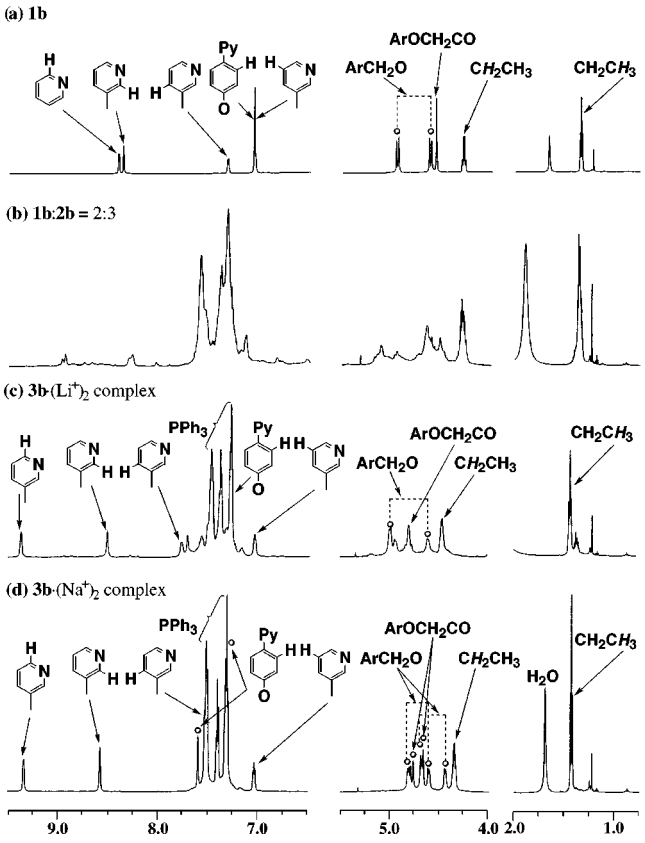


Figure 1. Partial ^{1}H NMR spectra of (a) [**1b**] (5.0 mM), (b) [**1b**]:[**2b**] = 2:3 (5.0 mM:7.5 mM), (c) [**3b**] (2.5 mM) in the presence of CF_3SO_3Li (15.0 mM), and (d) [**3b**] (2.5 mM) in the presence of CF_3SO_3Na (10.0 mM): $Cl_2CDCDCl_2$, 27 °C, 600 MHz.

Results and Discussion

Attempts to Construct a Dimeric Molecular Capsule from 1b and 2b. We previously reported that a mixture of 4-pyridyl calixarene **1a** and *cis*-Pd^{II} complex **2a** in a 2:3 ratio in $Cl_2CDCDCl_2$ gives a molecular capsule **3a** with D_{3h} symmetry, spectral evidence for which is obtained from the simple ^{1}H NMR splitting pattern.[12,13] A solution of a 2:3 **1b**/**2b** mixture, however, gave a very complicated and very broadened ^{1}H NMR spectrum (Figure 1b). This result suggests that an asymmetrical product was formed in the mixture, presumably because of the high flexibility of the homooxacalix[3]arene skeleton and the rotational freedom of 3-pyridyl groups. The rotation of the 4-pyridyl groups in **3a** does not affect the coordination geometry of the pyridine nitrogens, whereas that of the 3-pyridyl groups in **3b** does change the coordination geometry, resulting in the complex noncapsular molecules.

It is known that the conformational freedom remaining in homooxacalix[3]aryl ester derivatives can be frozen by com-

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plexation with appropriate metal cations resulting in a cone conformation with C_{3v} symmetry.[17] We have confirmed that **3b** is able to form a dimeric molecular capsule when the 3-pyridyl groups are appropriately preorganized by alkali metal cations complexed at the lower rim. The ^{1}H NMR measurements of **1b** with increasing CF_3SO_3Li or CF_3SO_3Na concentration showed that the chemical shift changes, induced by the metal binding to the lower rim ester groups, are saturated at $[CF_3SO_3M]/[\mathbf{1b}] > 1.5$. Also, we previously found that the chemical shift changes in **3a** are saturated at $[CF_3SO_3M]/[\mathbf{3a}] > 3.0$ (Figure S6).[18] We thus performed the ^{1}H NMR measurements for **3b** at $[CF_3SO_3M]/[\mathbf{3b}] = 4.0$ where 1 mol of **3b** should fully bind 2 mol of Li^+ or Na^+.

As shown in Figure 1c, a 2:3 **1b**/**2b** mixture gave a simple ^{1}H NMR splitting pattern in the presence of CF_3SO_3Li. The ^{1}H NMR spectrum consists of one kind of signal for the ArH, four pyridyl protons, $ArOCH_2CO$, and CH_2CH_3 protons, and a pair of doublets for the $ArCH_2O$ protons. This simple ^{1}H NMR spectrum implies that the **3b**·$(Li^+)_2$ complex has a D_{3h}-symmetrical structure. It is undoubted that Li^+ ions bound to the ionophoric lower rims enhance the symmetry of **3b**. The ^{1}H NMR spectrum of the **3b**·$(Na^+)_2$ complex is apparently similar to that of the **3b**·$(Li^+)_2$ complex. However, careful examination of Figure 1d reveals that there are two pairs of doublets for the $ArCH_2O$ protons (4.80 and 4.61, and 4.68 and 4.44 ppm with an integral intensity ratio of 1:1:1:1), two doublets for the $ArOCH_2CO$ protons (4.76 and 4.66 ppm with an integral intensity ratio of 1:1), and two singlets for the ArH protons (6.99 ppm; another peak overlaps with PPh_3 protons). These peak-splitting patterns are commensurate with the "twisted" capsular structure and assigned to either a mixture of the (*P*)- and (*M*)-enantiomers of **3b**·$(Na^+)_2$ or the mono-Na^+-complexed asymmetrical **3b**·Na^+. If the duplicate peak splitting is induced by the formation of a 1:1 **3b**/Na^+ complex, in which a Na^+ ion is bound to one of the two lower rim binding sites, the $ArOCH_2CO$ protons should appear as two singlets. This rationale is very unlikely, because the $ArOCH_2CO$ protons appear as double-doublets (Figure 2b). Furthermore, since all other protons are assignable to a single homooxacalix[3]arene structure, it is inconceivable that the **3b**·$(Na^+)_2$ complex consists of two unequivalent homooxacalix[3]arenes. One may consider, therefore, that the unique peak-splitting patterns are due to the twisting motion of three 3-pyridyl groups which has a rate slower than the NMR time-scale. Moreover, the splitting patterns of the $ArCH_2O$ and ArH protons show that all 3-pyridyl rings should incline in the same direction (i.e., toward the phenyl groups). The proposed structure of the **3b**·$(Na^+)_2$ complex is illustrated graphically in Figure 2a.

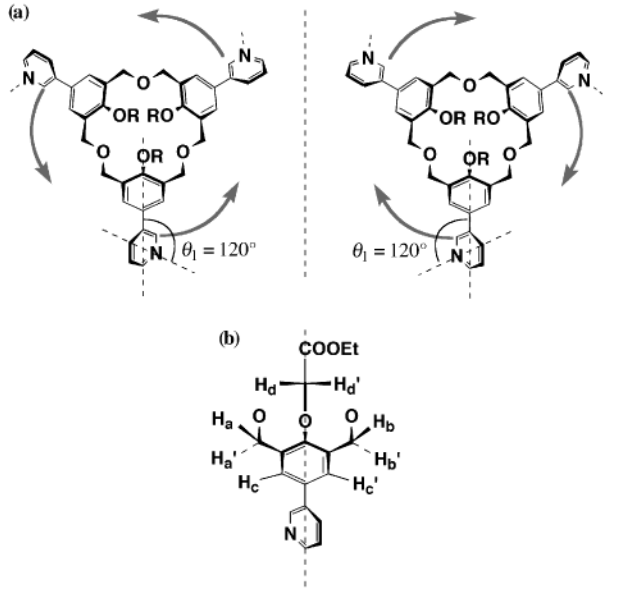

Figure 2. (a) Inclinations of pyridyl moieties related to phenyl units, proposed on the basis the ^{1}H NMR spectrum of **3b**·$(Na^+)_2$ complex. (b) Inequivalent protons present in one phenyl unit of **3b**·$(Na^+)_2$ complex.

Why do all three 3-pyridyl groups incline toward the same direction and apparently only in the **3b**·$(Na^+)_2$ complex? The phenylpyridyl−Pd^{II} angle (θ_1 in Figure 2a) must be 120° regardless of the dihedral angle between the pyridine ring and the phenol ring. On the other hand, the pyridyl−Pd^{II}−pyridyl angle (θ_2) must be 180°. In case Li^+ ions are bound to the lower rim, the interaction of the ethoxycarbonylmethoxy groups with the small Li^+ ion enforces the phenyl groups in the **1b**·Li^+ complex to be flattened.[17] Consequently, as the 3-pyridyl rings are nearly perpendicular to the phenyl rings, θ_1 and θ_2 can adopt their appropriate angles (i.e., 120° and 180°, respectively) in the **3b**·$(Li^+)_2$ complex (Scheme 1). On the other hand, in case Na^+ ions are bound to the lower rim, the interaction with the large Na^+ ion forces the phenyl rings in the **1b**·Na^+ complex to stand up.[17] Consequently, as long as the 3-pyridyl rings are perpendicular to the phenyl rings, θ_1 and θ_2 cannot adopt their appropriate angles in the **3b**·$(Na^+)_2$ complex (Scheme 1). To relieve the conformational strain, the 3-pyridyl groups have to rotate away from the perpendicular positions, and this twist eventually gives rise to the helical structure in the **3b**·$(Na^+)_2$ complex. The helical structure is well consistent with the splitting patterns obtained from the ^{1}H NMR measurements, that is the structures illustrated in Figure 2. Two enantiomers have one chiral axis per one pyridine, six chiral axes in total, as in the case with binaphthol.

To confirm that the **3b**·$(Na^+)_2$ complex consists of one pair of enantiomers, we measured the ^{1}H NMR spectra in the presence of chiral shift reagents. We tested Pirkle's reagent, (*S*)-2,2,2-trifluoro-1-(9-anthryl)enthanol (S_p), which is known to be most effective for other inherently chiral calix[*n*]arenes.[19] The ^{1}H NMR spectra of the **3b**·$(Li^+)_2$ and the **3b**·$(Na^+)_2$ complexes in the presence of Pirkle's reagent are shown in Figure 3. It is seen from Figure 3b that the peak for the pyridyl 6-H's of the **3b**·$(Na^+)_2$ complex splits into a pair with an almost

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(18) The formation of the **3b**/M^+ 1:2 complexes (**3b**·$(M^+)_2$) was confirmed by ESI-TOF MS and ^{1}H NMR spectroscopy. When a CH_2Cl_2 solution containing **3b** and Na^+ was measured, one peak appeared at 2314.5 [$m/z = (M + 2Na^+)/2$], which was assignable to the **3b**·$(Na^+)_2$ 1:2 complex ($M = 4629$) (Figure S5). The result suggests that the 1:2 complex is formed between **3b** and Na^+ in solution. When the ratio of $CF_3SO_3Na^+$ and **3b** was 1:1, the ^{1}H NMR spectra gave split peaks assignable to the **3b**·$(Na^+)_2$ 1:2 complex and noncapsular molecules of a **1b**/**2b** mixture in $Cl_2CDCDCl_2$ at 30 °C (Figure S6b). The complexation−decomplexation exchange rate of Na^+ is slower than the NMR time scale. All peaks observed in the ^{1}H NMR spectrum are assignable either to the **3b**·$(Na^+)_2$ 1:2 complex or to the noncapsular **1b**/**2b** mixture and no peak, assignable to the **3b**·Na^+ 1:1 complex appeared. Presumably, **3b** with the symmetrical capsular structure cooperatively binds two Na^+ by a positive allosteric effect. When the ratio was higher ($[CF_3SO_3Na^+]/[\mathbf{3b}] = 4.0$), the splitting pattern was simplified, which was assignable to the 1:2 complex with D_{3h}-symmetry. In the ^{1}H NMR spectrum of the Li^+ complex such clear peak splitting was not observed, but the chemical shifts gradually changed towards saturation. Since there is no reason the Li^+ binding must be saturated at the 1:1 stoichiometrical stage, one can consider that the **3b**/Li^+ 1:2 complex is also formed in the presence of excess $CF_3SO_3Li^+$.

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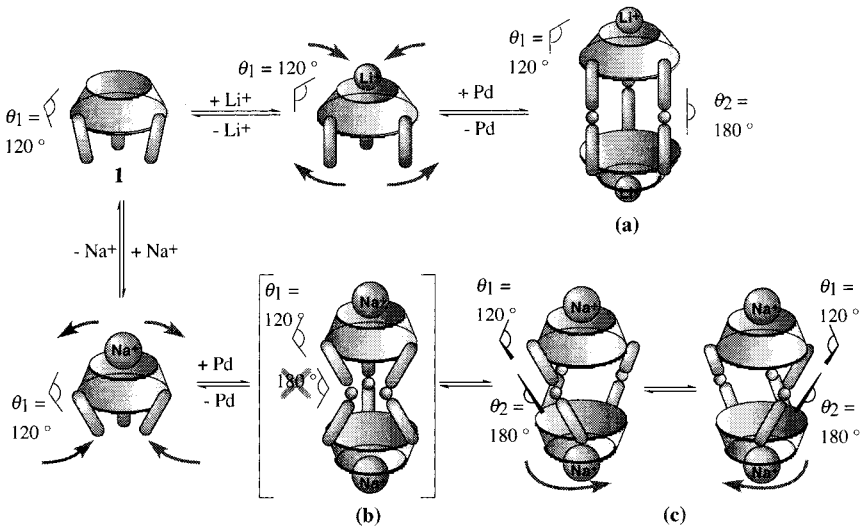
Scheme 1



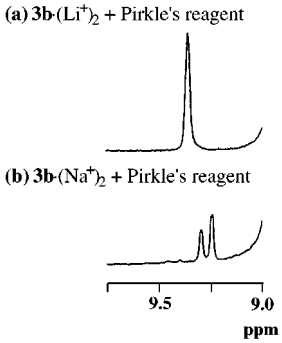


Figure 3. Partial ^{1}H NMR spectra of (a) **3b**·$(Li)_2$ complex and (b) **3b**·$(Na)_2$ complex in the presence of Pirkle's reagent ([**3b**] = 2.5 mM, $[CF_3SO_3Li]$ = 10.0 mM, $[CF_3SO_3Na]$ = 10.0 mM, [Pirkle's reagent] = 50.0 mM, $Cl_2CDCDCl_2$, 27 °C, 600 MHz).

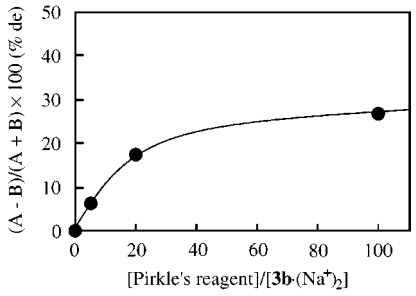


Figure 4. $(A - B)/(A + B) \times 100$ (% de) vs [Pirkle's reagent]/[**3b**·$(Na^+)_2$] plots in $Cl_2CDCDCl_2$ at 27 °C ([**3b**] = 2.5 mM, $[CF_3SO_3Na]$ = 10.0 mM; *A* and *B* denote the intensity of the higher magnetic field peak and the lower magnetic field peak, respectively, in the 3-pyridyl 6-positional protons.).

1:1 intensity ratio. Very interestingly, the intensity ratio $\{(A - B)/(A + B) \times 100$ (% de)$\}$[20] of the split peaks changes with the increase in the concentration of Pirkle's reagent (Figure 4). This finding suggests that the two possible diastereoisomers (*P*·S_P and *M*·S_P) of **3b**·$(Na^+)_2$ {(*P*)- and (*M*)-forms} show a different binding ability for Pirkle's reagent. For the highly symmetrical **3b**·$(Li^+)_2$ complex, in contrast, peak splitting was not induced by the addition of Pirkle's reagent (Figure 3a).

The formation of the **3b**·$(Na^+)_2$ complex was also supported by coldspray ionization mass spectrometery (CIS-MS, the measurable molecular weight <3000).[21] When CIS-MS was measured of a CH_2Cl_2 solution containing **1b**, **2b**, and CF_3SO_3Na in a 2:3:6 ratio, one strong peak appeared at 2314 [m/z = (M + 2Na)$^{2+}$/2], which is assignable to the **3b**·$(Na^+)_2$ complex (**3b**: M = 4582).

Inclusion of a Chiral Ammonium Guest in the Dimeric Molecular Capsule. It is known that the homooxacalix[3]aryl ester with a C_{3v}-symmetrical structure favorably bind RNH_3^+ ions, which also have a complementary C_{3v}-symmetrical structure.[22] It occurred to us that utilizing this guest-binding property, the chirality inherent to **3b** might be controlled by complexation with chiral R*NH_3^+ ions. We selected (*S*)-2-methylbutylammonium triflate (**4** or S_G) as such a candidate chiral guest.[23]

First, we estimated whether the molecular capsule really exists after complexation of **4** by **3b**. The formation of a **3b**−**4** complex was confirmed by ^{1}H NMR spectroscopy. As shown in Figure 5, the ^{1}H NMR spectrum of a 2:3 **1b**/**2b** mixture in the presence of **4** can be assigned to a **3b**−**4** complex, the splitting patterns of which are similar to those of the **3b**·$(Na^+)_2$ complex. Unexpectedly, a few new peaks appeared at remarkably high magnetic field (−0.05 to −1.75 ppm). The large upfield shift of these peaks suggests that the alkyl protons of **4** exist inside the cavity of **3b**, undergoing a shielding effect of the phenyl rings (Figure 6b).[15] The separation of these peaks from those of free **4** (2.94, 2.74, 1.71, 1.41, 0.99, and 0.93 ppm) implies that the complexation−decomplexation exchange rate is slower than the NMR time-scale. Because of the peak complexity of the ^{1}H NMR spectrum of bound **4**, the stoichi-

(20) *A* and *B* denote the intensity of the larger peak and the smaller peak, respectively, in the 3-pyridyl 6-H's: for example, in **3b**·$(Na^+)_2$ complex, *A* = the intensity of the higher magnetic field peak; in **3b**·**4**$_2$ complex in the presence of (*S*)-isomer of Pirkle's reagent, *A* = the intensity of the lower magnetic field peak; in **3b**·**4**$_2$ complex in the presence of (*R*)-isomer of Perkle's reagent, *A* = the intensity of the higher magnetic field peak. At present, we cannot assign which helicity is the (*P*)- or (*M*)-form. Therefore, it is impossible to compare ± signs between Figures 4 and 7.

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(23) We have performed ^{1}H NMR measurements of **3b** in the presence of each aromatic chiral ammonium ion, (*R*)-benzyloxycarbonylphenyl methylammonium triflate (**5**) and (*S*)-1-phenylethylammonium triflate (**6**). The complicated ^{1}H NMR spectra obtained from these **3b**·**5** and **3b**·**6** complexes (Figure S3) suggest that the complexes do not have a symmetrical structure. We could not assign these complex peaks. Therefore, we used (*S*)-2-methylbuthylammonium triflate (**4**), which lacks an aromatic substituent.

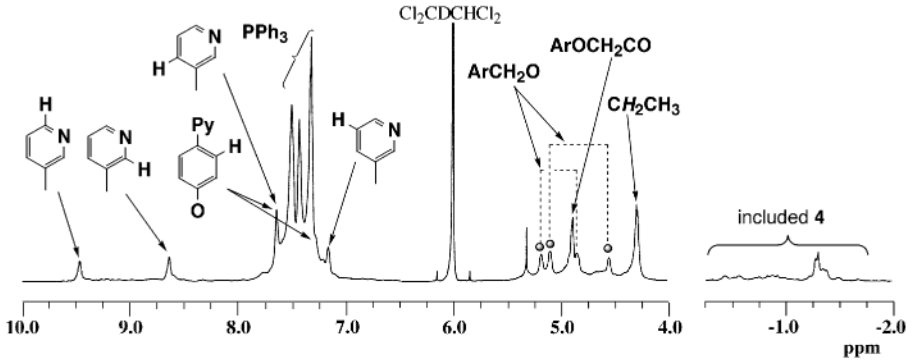


Figure 5. ^{1}H NMR spectrum of [**3b**] (1.0 mM) in the presence of **4** (5.0 mM): $Cl_2CDCDCl_2$:CD_3OD = 24:1 (v/v), 27 °C, 600 MHz.

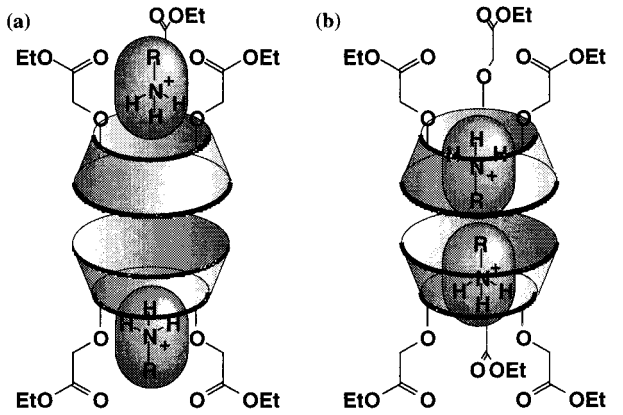


Figure 6. Two possible interactions between homooxacalix[3]aryl ester and R*NH_3^+.

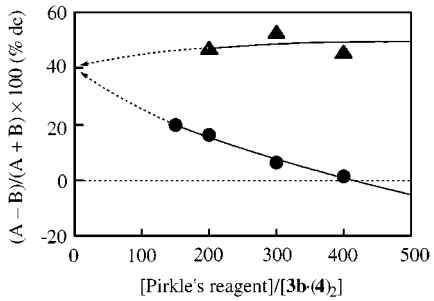
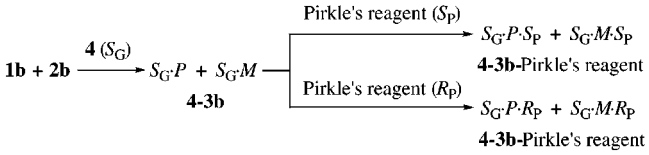


Figure 7. $(A - B)/(A + B) \times 100$ (% de) vs [Pirkle's reagent]/[**3b**·**4**$_2$] plots in $Cl_2CDCDCl_2$:CD_3OD = 24:1 (v/v) at 27 °C ([**3b**] = 1.0 mM, [**4**] = 5.0 mM. In the case of the (*S*)-isomer, *A* and *B* denote the intensity of the lower magnetic field peak and the higher magnetic field peak, respectively, in the 3-pyridyl 6-positional protons; on the other hand, in the case of the (*R*)-isomer, *A* and *B* denote the reverse assignment; ●: (*S*)-isomer and ▲: (*R*)-isomer of Pirkle's reagent).

Scheme 2



ometry between **3b** and **4** could not be determined precisely. Hence, we compared the peak intensities of the ^{1}H NMR spectrum of **3b** with free **4** and obtained evidence that the stoichiometry of **3b**/**4** is 1:2 {[**3b**] = 1.0 mM, [included **4**] = [total **4**] − [free **4**] = 5.0 − 2.8 = 2.2 mM}.

Second, we have determined the diastereomeric excess (de) of **3b** in the presence of chiral guest **4**. When **4** was added to **3b**, the ^{1}H NMR spectrum showed peaks with a splitting pattern very similar to that of the **3b**·$(Na^+)_2$ complex (Figure 5). As shown in Figure 5, the $ArCH_2O$ proton signals appear as two pairs of doublets at 5.18 and 4.56, and 5.10 and 4.85 ppm, respectively. However, peak splitting for the two possible diastereoisomers S_G·*P* and S_G·*M* in the **3b**·**4**$_2$ complex, as observed in the ^{1}H NMR spectrum of the **3b**·$(Na^+)_2$ complex in the presence of Pirkle's reagent, was not observed. This is probably because **4**, unlike Pirkle's reagent, lacks an aromatic ring, which exerts an efficient shielding effect. To obtain an insight into the stoichiometry, Pirkle's reagent was added to the **3b**·**4**$_2$ complex. Addition of the (*S*)-isomer of Pirkle's reagent (S_P) should yield two possible diastereoisomers of **3b**·**4**$_2$, namely S_G·*P*·S_P and S_G·*M*·S_P (Scheme 2). In fact, the peak splitting was observed for the pyridyl 6-positional protons of the **3b**·**4**$_2$ complex (1.0 mM) in the presence of Pirkle's reagent (≥150 mM) (Figure S4). Figure 7 shows a plot of the concentration of Pirkle's reagent versus the intensity ratio of split peaks $\{(A - B)/(A + B) \times 100$ (% de)$\}$.[20] Since the intensity ratio of split peaks decreases with the addition of Pirkle's reagent, one can estimate the ratio of S_G·*P* and S_G·*M* in the absence of Pirkle's reagent by extrapolating the plots in Figure 7. This leads to an estimated de of 40%, that is, S_G·*P*:S_G·*M* = 7:3 or 3:7. Furthermore, this intensity ratio (% de) was reconfirmed by ^{1}H NMR measurements in the presence of (*R*)-Pirkle's reagent (R_P). Presence of the (*R*)-isomer should yield two possible diastereoisomers of **3b**·**4**$_2$, namely S_G·*P*·R_P and S_G·*M*·R_P, as shown in Scheme 2. Addition of the (*R*)-isomer separated the 3-pyridyl 6-H's, the intensity of the peak at higher magnetic field being highest. This trend is opposite to the result obtained by the addition of (*S*)-isomer. However, the extrapolated intensity ratio (% de) is nearly the same as that obtained in the (*S*)-isomer case, (i.e., 40% de: Figure 7). The agreement of the extrapolated values establishes that **3b** complexed with **4** has a chirally twisted structure. At present, it is still difficult to determine whether the induced helicity is the (*P*)- or (*M*)-form.

Third, we confirmed the helicity of the **3b**·**4**$_2$ complex by circular dichroism (CD) spectroscopy (Figure 8). In $Cl_2CDCDCl_2$ at 25 °C, compounds **1b** and **3b** were, of course, CD-silent whereas a distinct CD band appeared in the presence of **4**. In the **1b**·**4** complex, the induced CD (ICD) band appeared in the region below 280 nm. In the **3b**·**4**$_2$ complex, the split CD band, which crosses the $[\theta] = 0$ line at 290 nm, is ascribed to an exiton coupling. These findings reveal that the enantiometric ratio of **3b** is controllable by complexation with chiral **4**.

Conclusions

In conclusion, the present paper demonstrated a novel system, in which a capsule-like cage molecule was almost quantitatively constructed in a self-assembled manner by the addition of

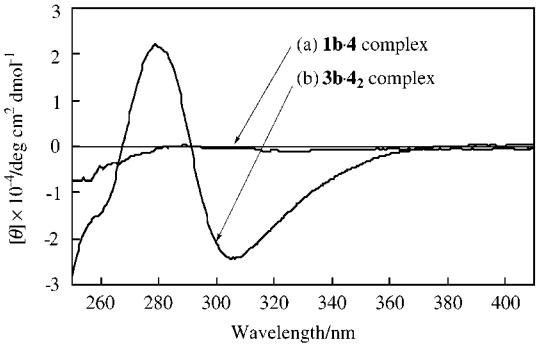


Figure 8. CD spectra of (a) **1b·4** ([**1b**] = 2.0 mM, [**4**] = 5.0 mM) and (b) **3b·4**$_2$ complex ([**3b**] = 1.0 mM, [**4**] = 5.0 mM): $Cl_2CHCHCl_2$: CH_3OH = 24:1 (v/v), 25 °C.

appropriate metal or ammonium ions. The ^{1}H NMR spectrum of a 2:3 **1b**/**2b** mixture in the presence of CF_3SO_3Li can be assigned to a **3b**·$(Li^+)_2$ complex with D_{3h} symmetry. On the other hand, **3b** shows a chiral twisting motion in the presence of larger Na^+ and RNH_3^+ ions. Also interesting is the finding that the helicity of **3b** is controllable by the addition of Pirkle's reagent or chiral $R^*NH_3^+$ ions. Although the correlation between (*M*) versus (*P*) helicity in **3b** and (*R*) versus (*S*) chirality in Pirkle's reagent is not yet clear, this twisting phenomenon is undoubtedly a new method to provide chiral self-assembled molecular capsules. The diastereomeric excess (% de) was relatively high, which suggests that higher optical purity would be achieved by inclusion of bulkier chiral $R^*NH_3^+$ ions. The applications of these systems are continued to be studied in our laboratories.

Experimental Section

Miscellaneous. Melting points were determined on a Micro Melting Point Apparatus (Yanaco MP-500D) and are uncorrected. ^{1}H NMR spectra were measured on a Bruker DRX 600 spectrometer. CD spectra were recorded with a JASCO J-720WI CD spectrometer.

Materials. The synthesis of diethyl(4-pyridyl)borane was described previously.[24] Compounds **2b** and **4** were synthesized from *trans*-Pd$(PPh_3)_2Cl_2$ and 2-$MeBuNH_3Cl$, respectively, by exchanging the anion in the presence of excess CF_3SO_3Ag in dry CH_2Cl_2.

Preparation of 7,15,23-Tri-*m*-pyridyl-25,26,27-tris[(ethoxycarbonyl)methoxy]-2,3,10,11,18,19-hexahomo-3,11,19-trioxacalix[3]arene (1b). 7,15,23-Tribromo-25,26,27-tris[(ethoxycarbonyl)methoxy]-2,3,10,11,18,19-hexahomo-3,11,19-trioxacalix[3]arene[17] (0.20 g, 0.25 mmol) was dissolved in 20 mL of 1,2-dimethoxyethane, and to this solution were added diethyl(3-pyridyl)borane (0.11 g, 0.73 mmol), cesium fluoride (0.20 g, 1.32 mmol), and tetrakis(triphenylphosphine)-palladium(0) (0.02 g, 0.02 mmol). The mixture was stirred at reflux temperature for 5 h. After cooling, the reaction mixture was filtered, and the filtrate was washed twice with water and dried over $MgSO_4$. After evaporation to dryness, the residue was purified by preparative TLC on silica gel using acetone:ethanol:chloroform = 1:1:10 (v/v/v) as an eluent: yield, 53% (0.12 g); mp 48.5−51.3 °C; ^{1}H NMR (600 MHz, $Cl_2CDCDCl_2$) δ 8.41 (d, 1H, 6-PyH, J = 4.4 Hz), 8.36 (s, 1H, 2-PyH), 7.32 (d, 1H, J = 7.6 Hz, 4-PyH), 7.06−7.04 (m, 3H, 5-PyH, ArH), 4.94 (d, 2H, J = 13.1 Hz, $ArCH_2O$, *ax*), 4.62 (d, 2H, J = 13.1 Hz, $ArCH_2O$, *eq*), 4.56 (s, 2H, $ArOCH_2$), 4.29 (q, 2H, J = 7.1 Hz, CH_2CH_3), 1.35 (t, 3H, J = 7.1 Hz, CH_2CH_3). Anal. Calcd for $C_{51}H_{51}O_{12}N_3$·0.5$CHCl_3$: C, 67.49; H, 5.66; N, 4.62. Found: C, 67.45; H, 5.79; N, 4.68.

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Supporting Information Available: Figures of ^{1}H NMR and CSI-TOF MS spectra (PDF). This material is available free of charge via the Internet at http://pubs.acs.org.

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