CHEMISTRY LETTERS, pp. 2269-2272, 1987.

Induced Circular Dichroism in Calixarene Complexes

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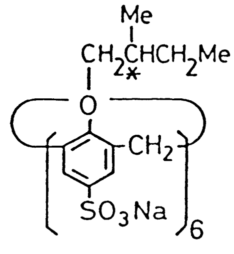
The induced circular dichroism (ICD) spectra were applied to the estimation of host-guest-type interactions of water-soluble calixarenes. It was found that certain azo-dye stuffs give the ICD spectra in the presence of a chiral calixarene, 5,11,17,23,29,35-hexasulfonato-37,38,39,40,41,42-hexakis((S)-2-methylbutyloxy)calix[6]arene and p-nitrocalix[6]arene and p-nitrocalix[8]arene give the ICD spectra upon complexation of a chiral guest, (R)-1,1'-binaphthyl-2,2'-phosphoric acid but p-nitrocalix[4]arene is absolutely silent.

The CD technique is one of the most useful tools to evaluate asymmetric interactions between host and guest molecules in solution. To detect the asymmetric host-guest complexation spectrophotometrically there exist four different combinations: that is, (a) chiral, chromophoric host with guest, (b) host with chiral, chromophoric guest, (c) chromophoric host with chiral guest, and (d) chiral host with chromophoric guest. Types (a) and (b) are detected as a change in the CD spectra whereas types (c) and (d) are detected as a change in the ICD spectra. It is known that the cyclodextrin cavity, which is made up of D-glucopyranose units and therefore a priori chiral, gives the ICD spectra upon inclusion of proper chromophoric guest molecules.[1-5] This corresponds to type (d) in the above classification.

Recently, we have been devoting our research effort toward functionalizations of water-soluble calixarenes which have a hydrophobic cavity made up of benzene units.[6] Although it is considerably difficult to find evidence for solulition complexes in organic solvents,[7] these water-soluble calixarenes have provided several lines of unambiguous evidence for the complex formation in an aqueous system.[8-10] It occurred to us that if the achiral calixarene cavity is adequately modified with chiral substituents, it may serve as a chiral reaction field, like cyclodextrins,[1] useful for the molecular recognition and the asymmetric synthesis. In this paper we report that certain azo-dye stuffs (**3**:R) included in a chiral calixarene (**1**) (5,11,17,23,29,35-hexasulfonato-37,38,39,40,41,42-hexakis((S)-2-methylbutyloxy)calix[6]arene) give the ICD spectra and among p-nitrocalix[n]arenes (**2**:n), the hexamer (**2**:n=6) and the octamer (**2**:n=8) give the ICD spectra upon complexation of a chiral guest (**4**)((R)-1,1'-binaphthyl-2,2'-phosphoric acid), while the tetramer (**2**:n=4) is absolutely silent.



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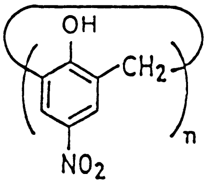

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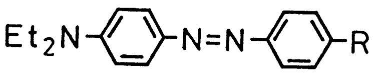

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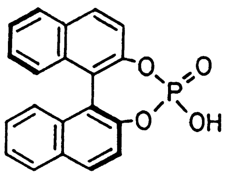

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The calixarene **1** was synthesized from (S)-1-bromo-2-methylbutane and calix[6]arene-p-hexasulfonate in a manner similar to that described previously.[9] The synthetic method for **2**:n will be described in detail.[11] These calixarenes were identified by IR, ^{1}H-NMR, and elemental analysis. By the use of the conductance method[9] the critical micelle concentration (CMC) of **1** was estimated to be 1.1×10^{-3} mol dm^{-3} at 20 °C. Thus, subsequent experiments were carried out below this CMC.

Seven 4-substituted-4'-diethylaminoazobenzenes (**3**:R) were tested as achiral chromophoric guests which might show the ICD spectra in the presence of chiral **1**. We found that among seven dye stuffs (**3**:R=OMe, NMe$_2$, Me, SO$_2$Me, NO$_2$, CN and 3-nitro-4'-diethylaminoazobenzene) only two guests **3**:NO$_2$ and **3**:CN give the ICD spectra in water (Fig. 1)[11]: [θ] 14000 (402 nm) and -1900 (430 nm) for **2**:NO$_2$ and 9000 (347 nm) and -6100 (328 nm) for **2**:CN. The finding suggests that **1** can include **3**:NO$_2$ and **3**:CN in the cavity and that these guests are located in the neighborhood of the chiral (S)-2-methylbutyl groups.

The most important and urgent subject in calixarene chemistry would be to clarify whether calixarenes show the molecular-recognition ability like cyclodextrins. This would be conveniently tested by the ICD studies. We measured the CD spectra of chromophoric **2**:n[12,13] in the presence of various chiral guest molecules.[14] Among them **4** afforded the distinct ICD spectra shown in Fig. 2. Interestingly, the greatest [θ] values were observed for **2**:n=6 ([θ]= -19000 (392 nm), 2400 (450 nm)) and the next was for **2**:n=8 ([θ]=-5900 (410 nm)). In contrast, the ICD band was not detected at all for **2**:n=4. As shown by a

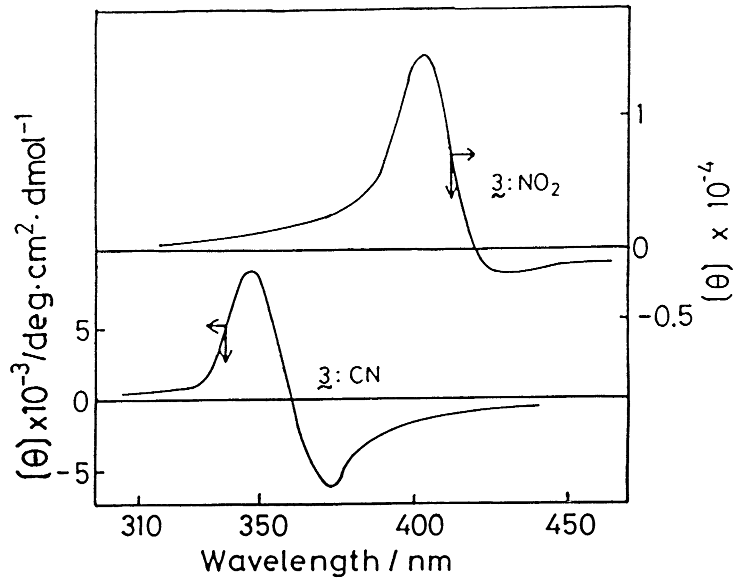

Fig. 1. ICD spectra of **3**:NO$_2$ and **3**:CN in the presence of **1**. 23 °C, pH 6.9 with 0.067 mol dm^{-3} phosphate, [**3**:NO$_2$] = [**3**:CN] = 1.20 × 10^{-4} mol dm^{-3}, [**1**] = 1.00 × 10^{-3} mol dm^{-3}, path length 1.0 mm. The absorption spectra have been reported.[12,13)]

continuous variation method (Fig. 3), **4** and **2**:n=6 form a 1:1 complex. The results clearly indicate that **4** fits the cavity of **2**:n=6 (and probably of **2**:n=8) but is too large to be included in the cavity of **2**:n=4. On the basis of X-ray studies[7)] and CPK molecular models the upper-rim diameters of calix[4]arene and calix[6]arene are estimated to be 3.8 Å and 5.0 Å, respectively. Therefore, the molecular recognition pattern of calix[6]arene and its derivatives would be comparable with that of β-cyclodextrin (diameter 5.5-5.9 Å).

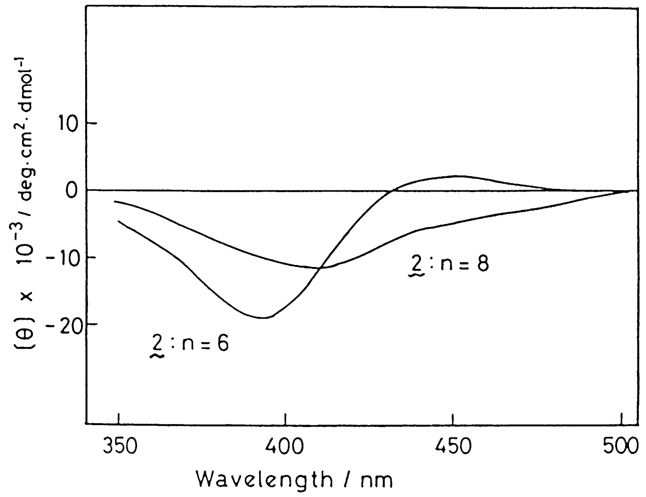

Fig. 2. ICD spectra of **2**:n=6 and **2**:n=8 in the presence of **4**. 20 °C, pH 12.8 with 0.07 mol dm^{-3} NaOH, [**2**:n=6] = 1.00 × 10^{-4} mol dm^{-3}, [**2**:n=8] = 1.20 × 10^{-4} mol dm^{-3}, [**4**] = 7.70 × 10^{-3} mol dm^{-3}, path length 1.0 mm.

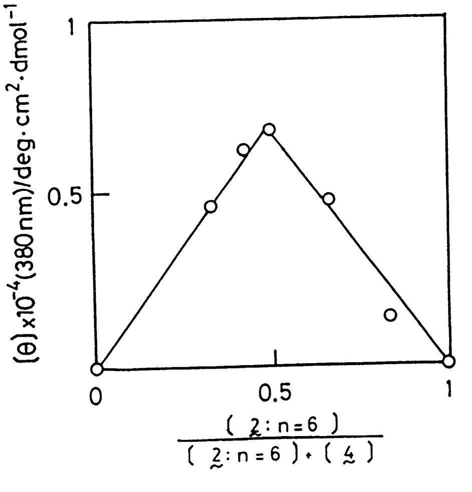

Fig. 3. Continuous variation plot for **4** + **2**:n=6. 20 °C, pH 12.8 with 0.07 mol dm^{-3} NaOH, [**4**] + [**2**:n=6] = 6.00 × 10^{-4} mol dm^{-3}, path length 0.1 mm.

In conclusion, the present study demonstrated for the first time that the host-guest type interactions between chiral calixarene and chromophoric guest (type (d)) and between chromophoric calixarene and chiral guest (type (c)) can be estimated with the ICD method. Through this study, it was newly established that the calixarene cavity is capable of molecular recognition in an aqueous system. This suggests the broad utility of calixarenes, for example, in designing enzyme mimics and catalyzing asymmetric reactions.

References

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11) λ_{max} in water: 416 nm for **3**:NO_2 and 394 nm for **3**:CN. The absorption maxima of **3**:R shift to longer wavelengths with the increase in the solvent polarity (for example, 489 nm in methanol and 453 nm in hexane for **3**:NO_2), but those in water shift unusually to shorter wavelengths. This suggests that these dye stuffs form aggregates in water. The λ_{max} values in ICD imply that aggregated **3**:R is bound to **1**. Conceivably, **3**:R with push-pull substituents easily forms these aggregates.
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14) The chiral guests tested herein in addition to **4** are N,N-dimethyl-1-phenylethylamine, N,N,N-trimethyl-1-phenylethylammonium chloride, 1,1'-binaphthol, N-acetyl-L-tryptophanamide, 3-heptafluorobutyryl-(+)-camphor, N-α-methylbenzylnicotinamide, etc.

(Received August 27, 1987)