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Note

Reinvestigation of the structure of the pyrene-1-carboxylic acid–heptakis(2,6-di-*O*-methyl)cyclomaltoheptaose complex in water

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A revised structure of the inclusion complex of pyrene-1-carboxylate anion (**1**)–heptakis(2,6-di-*O*-methyl)cyclomaltoheptaose (**2**) in water is presented.

Analysis of circular dichroism (cd) spectra led one of us to report that cyclodextrins (CD) form novel capped-type nonbonded complexes with aromatic compounds[1,2]. To determine if these complexes are really capped and, if so, on which side of the CD cavity the aromatic compound lies, we examined the nuclear Overhauser effect (NOE) between host and guest[3,4]. We used ROESY spectra for the NOE experiment, because the ROESY signal intensity does not depend greatly on the relaxation time of corresponding nuclei[5]. However, most of the complexes, which were described[1,2] as being capped, did not show NOE signals between host and guest under our experimental conditions. However, we found NOE signals between protons of **1** and the 3-, 5-, and 6-*O*-methyl protons of **2** for solutions in D_2O at pH 9.4 (direct reading from a pH meter). This fact indicated that **1** was not capped but lay inside the CD cavity under our experimental conditions. In the ROESY experiment, the concentrations of host and of guest were both 9 mM, which is a much higher concentration than that used in the cd measurements. Accordingly, we measured the NOE difference-spectrum of the complex at 10 μM concentration with the CAMELSPIN method[6] and observed NOE signals between aromatic protons of **1** and the 3 and 5 protons and 2- and 6-*O*-methyl protons of 2 (Fig. 1).

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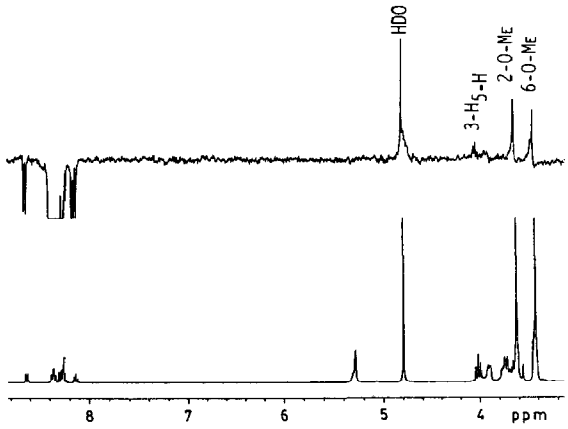

Fig. 1. The 400-MHz NOE difference spectrum of the 1–CD complex at 10 μM, pH 9.2 (without correction). Mixing time 300 ms. Signal assignments are based on ref 2. (J FX-400 spectrometer).

The previous paper[2] described one side of the large hydrophobic aromatic nucleus as facing the CD cavity and the other side as facing the aqueous medium. This explanation appears unreasonable, because such a large, hydrophobic plane of the pyrene aromatic nucleus is not likely to face the aqueous medium. Furthermore, the previous paper[2] showed that the cd and UV spectra of the complex exhibited greater fine structure in water than in chloroform. This fact shows that the guest molecule in water is in more of a nonpolar environment than it is in chloroform, in contrast to the general principle. The cd (Fig. 2) spectrum showed that these intensities were less than 1 mdeg. These values are almost at the sensitivity limit of the old spectrometer used in the previous paper[2], which has no

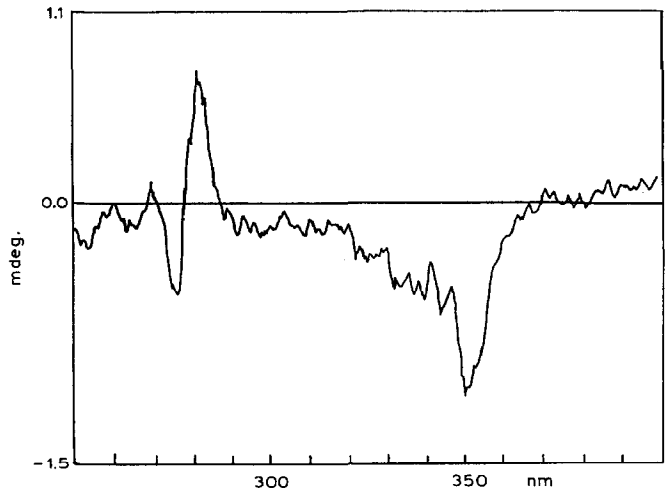

Fig. 2. The cd spectrum of the 1–CD complex in water at 20 mM of 2 and 75 μM of 1, pH 9.1.

TABLE I

The calculated transition moments of PYC based on the CNDO/S method.

Excitation energy (eV)	Calculated oscillator strength	Angle [a] (degree)	Symmetry
3.55	0.949	+5.5	A′ ← A′
3.73	0.048	−5.5	A′ ← A′
4.49	0.004	−44.5	A′ ← A′
4.74	0.051	−100.5	A′ ← A′
4.90	0.893	−90.0	A′ ← A′

[a] Angles against the y axis in Fig. 3a.

data-accumulation system. We therefore repeated the c.d. using a more advanced and sensitive spectrometers (J J-720 spectrodichrometer), which is at least 10 times more accurate than the one previously used[2]. Eight scans of data accumulation were used. A profile of the entire spectrum was almost a mirror image of the cd spectrum of the CD complex of pyrene itself, which is described[7] as an inclusion complex of the long axis of pyrene along the molecular axis of CD. As is evident from Fig. 2, the cd spectrum in the longest wavelength region gave a negative peak extending to only 290 nm, which is considered to arise from more than two $\pi \rightarrow \pi^*$ transitions. Below 290 nm, the complex exhibited a complicated spectrum, which was interpreted as originating from transitions that are basically electronic and/or vibrational. It is noteworthy, however, that the cd spectrum gave a positive band with its maximum at ~ 280 nm, which was different in sign from the previous data[2]. Calculated transition energies, based on the CNDO/S method, of pyrene-1-carboxylic acid (PYC) are summarized and listed in Table I, along with calculated oscillator strengths, polarization directions, and types of transition. The first A′ ← A′ transition was predicted to be at 3.55 eV and assigned to the negative cd band with its maximum at 350 nm. The observed broad negative cd curve, extended to 290 nm, was considered to come from the second electronic transition A′ ← A′, which is polarized along the long (y) axis. The third electronic transition, calculated to be at 4.49 eV, was polarized within the x–y plane, with the angle of polarization at 45° to the x or y axis. A dispersive cd signal at ~ 280 nm may be interpreted to result from the superposition of two vibronic cd bands, namely a positive cd band due to the long axis-polarized component on the one hand, and a negative cd band due to the short axis-polarized component on the other. A negative cd region of wavelength < 270 nm indicated several electronic transitions, for example, the transitions of A′ ← A′ predicted at 4.74 eV and A′ ← A′ at 4.90 eV. They are polarized along the shorter (x) axis, although they are theoretically expected to exhibit positive cd signals. Sign reversal may occasionally take place via vibrational coupling with electronic states.

The present experimental results showing NOE between the host and guest molecules, with a positive cd signal at 280 nm, lead us to conclude that the

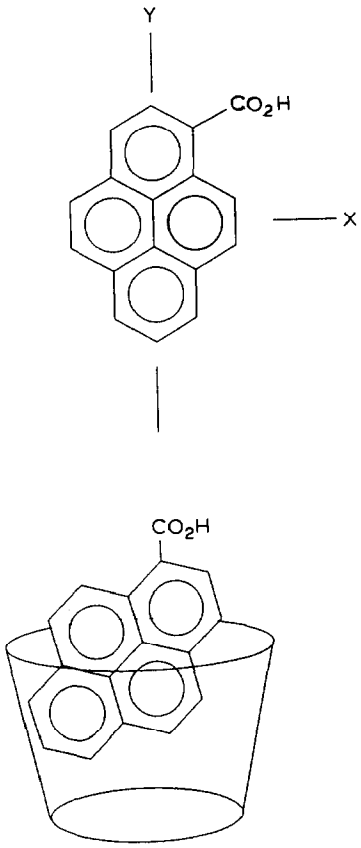

Fig. 3. Suggested mode for complexing of **1** with CD.

complex of **1** with **2** is not capped but is partially included in the cavity of the host molecule and inclined at more than 60°, nearly orthogonal to the molecular axis of the CD (Fig. 3). This accords with the theory[8,9] that a cd signal is positive when the angle between the $\pi \rightarrow \pi^*$ transition-moment of the guest molecule and the molecular axis of the CD is in the range between 0 and 54°.

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