Induced Circular Dichroism of Two Chromophores Included in γ-Cyclodextrin

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Synopsis. Induced circular dichroism (ICD) has suggested that γ-cyclodextrin (γ-CDx) accommodates two molecules of naphthalene and its derivatives with nearly axial inclusion but that it includes two Acridine Orange (AO) molecules with *S*-helicity.

In contrast to α- and β-CDxs which form mainly one host-one guest complexes with small arenes,[1] recent fluorescent studies have suggested that γ-CDx can include two arene molecules.[2-5] However, only a few studies have appeared on the ICD of two arene molecules in γ-CDx,[6-9] although ICD has been substantiated to be a powerful approarch to elucidate types of inclusion and configuration of arene molecules in CDxs.[10,11] Quite recently, we have shown that two pyrene molecules trapped in γ-CDx have *S*-helicity.[7,8] In this report, we describe the results for ICD of AO and naphthalene and its derivatives in the presence of γ-CDx.

Experimental

Materials. Naphthalene and its derivatives were recrystallized several times from appropriate solvents. 3,4-Bis[2-[2-(2-naphthyloxy)ethoxy]ethoxy]benzoic acid (**1**) was prepared in this laboratory.[12] AO (Chroma 1B-307, Germany) was purified according to the literature method.[13] γ-CDx was provided by Dr. N. Nakamura.

Measurements. Fluorescence spectra were recorded on a Shimadzu RF-500 spectrofluorophotometer, absorption spectra on a Shimadzu UV-360 spectrophotometer, and ICD spectra on a JASCO J-400X spectropolarimeter with a DP-500 data-processor at ambient temperature.

Results and Discussion

Figure 1 shows the absorption and ICD spectra of the γ-CDx–AO system. Absorption peaks appeared at 204, 230, 265, and 463 nm. Although the band position and shape of AO are known to be sensitive to temperature, ionic strength, and pH of the solution,[14,15] the present system seems to be composed mainly of dimeric AOs with a little amount of aggregated AOs. This is due to the fact that the bands of monomeric, dimeric, and aggregated AOs occur at *ca.* 490, 470, and 450 nm, respectively.[14,16] In the ICD spectrum, a curve with a change in sign from plus to minus and further to plus viewing from the longer wavelength side was observed in the visible region. As seen, two cross points well correspond to the absorption shoulder and/or peak. These facts indicate that this ICD originates from a dipole coupling between two AO molecules in γ-CDx. The situation is also the same for the UV region. Since the bands at 265 and 463 nm are both assigned to a polarization along the long axis,[17] the results of above ICD indicate that the two AO molecules are included in γ-CDx with *S*-helicity.

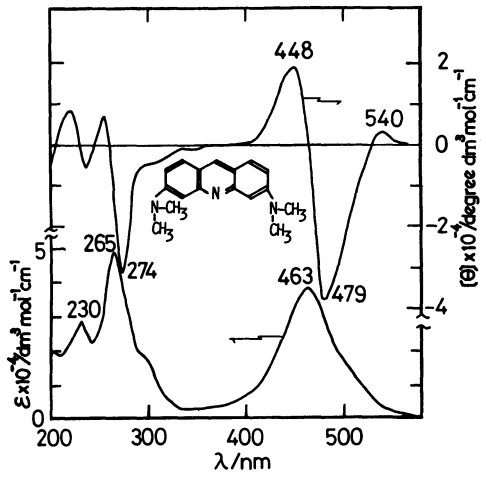

Fig. 1. Absorption (bottom) and ICD (top) spectra of AO in the presence of γ-CDx. [AO]/mol·l^{-1} = 1 × 10^{-4}, [γ-CDx]/mol·l^{-1} = 10^{-2}, Solvent: 0.5 mol·l^{-1} phosphate buffer, pH 6.1. Pathlength: 0.2 mm.

Two-guest inclusion of naphthalene and its derivatives into γ-CDx was examined similarly. The results for naphthalene and **1** are demonstrated in Figs. 2 and 3, respectively. As revealed, the intensity ratio of excimer/monomer fluorescence (ratio of emission at 396/334 nm) of naphthalene was larger for a system containing γ-CDx than that containing β-CDx, suggesting inclusion of more than one naphthalene in γ-CDx. Although a monomer fluorescence had still a comparable intensity as that of excimer, ICD spectrum was measured in the presence of γ-CDx. Simple peaks or troughs were

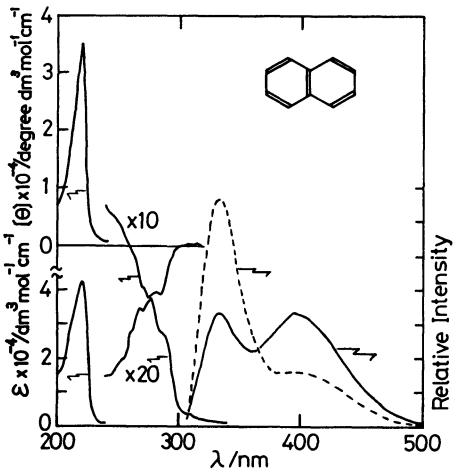

Fig. 2. Absorption (left bottom), ICD (left top), and fluorescence (right) spectra of naphthalene in the presence of γ-CDx (solid line) or β-CDx (dotted line). [naphthalene]/mol·l^{-1} = 1.2 × 10^{-4}, [γ-CDx]/mol·l^{-1} = [β-CDx]/mol·l^{-1} = 10^{-2}. Solvent: 0.1 mol-l^{-1} phosphate buffer, pH 6.8. Pathlength: 10 mm except for 200—240 nm region (1 mm). In the fluorescence spectra, excitation was at 290 nm.

observed nearly accurately at the wavelengths where ^1L_b, ^1L_a, and ^1B_b transitions appear, but a dipole coupling type spectrum was not recognized.

To clarify the features in Fig. 2, **1** was used (Fig. 3).

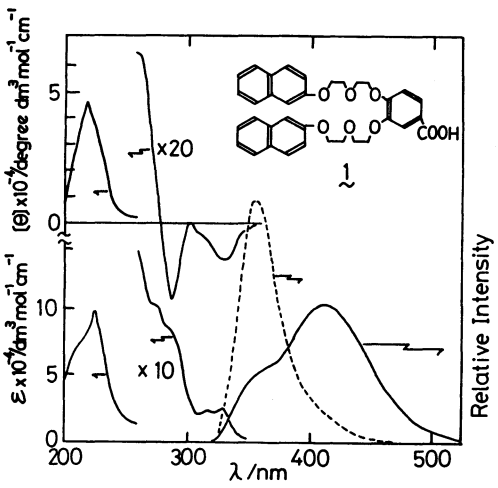

Fig. 3. Absorption (left bottom), ICD (left top), and fluorescence (right) spectra of **1** in the presence (solid line) or absence (dotted line) of γ-CDx. [**1**]/mol·l^{-1}= 1.1×10^{-4}, [γ-CDx]/mol·l^{-1}=10^{-2}. Solvent: 0.1 mol·l^{-1} borate buffer, pH 9.2. Pathlength: 10 mm except for 200—260 nm region (1 mm). In the fluorescence spectra, excitation was at 290 nm.

As shown, **1** showed only monomer fluorescence in the absence of γ-CDx. However, by the addition of γ-CDx, it revealed mainly excimer fluorescence alone, suggesting the inclusion of two naphthalene moieties. The ICD spectrum of this solution showed a single peak associated with the ^1B_b transition. For the interpretation of this phenomenon, two possibilities are deduced. One is that two naphthalene moieties are trapped with their long axes nearly parallel to each other, and another is that even two naphthalene moieties of **1** are not so much bulky for the large cavity of γ-CDx so that it may not have a fixed configuration to produce a clear dipole coupling type spectrum. However, the latter possibility may be small because free movement of the naphthalene moieties of **1** in γ-CDx is restricted by the alkyl chain connecting them.

After convincing the fair development of excimer fluorescence by the addition of γ-CDx, we measured also the ICD spectra of 1- or 2-naphthylacetic acid, 1- or 2-naphthoic acid, and 1- or 2-(naphthyloxy)acetic acid. However, in no case was found a dipole coupling type spectrum.

One plausible reason for the above difference in the ICD spectra between AO and naphthalene derivatives might be ascribed to the difference of the character of guest molecule themselves such as sizes and tendency toward aggregation.

Thus, the ICD spectroscopy coupled with electronic absorption or fluorescence spectroscopy has suggested that γ-CDx accepts two Acridine Orange molecules with *S*-helicity, but that it accommodates two naphthalene molecules with nearly axial inclusion.

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References

1) M. L. Bender and M. Komiyama, "Cyclodextrin Chemistry," Springer-Verlag, Berlin (1978).
2) A. Ueno, K. Takahashi, and T. Osa, *J. Chem. Soc., Chem. Commun.*, **1980**, 921; **1981**, 95, 194.
3) J. Emert, D. Kodali, and R. Catena, *J. Chem. Soc., Chem. Commun.*, **1981**, 758.
4) N. J. Turro, T. Okubo, and G. C. Weed, *Photochem. Photobiol.*, **35**, 325 (1982).
5) K. Kano, T. Takenoshita, and T. Ogawa, *J. Phys. Chem.*, **86**, 1833 (1982).
6) N. Kobayashi, A. Ueno, and T. Osa, *J. Chem. Soc., Chem. Commun.*, **1981**, 340.
7) N. Kobayashi, R. Saito, Y. Hino, A. Ueno, and T. Osa, *J. Chem. Soc., Chem. Commun.*, **1982**, 706.
8) N. Kobayashi, R. Saito, H. Hino, Y. Hino, A. Ueno, and T. Osa, *J. Chem. Soc., Perkin Trans. 2*, in press.
9) N. Kobayashi, R. Saito, A. Ueno, and T. Osa, *Makromol. Chem.*, **1983**, 184.
10) H. Shimizu, A. Kaito, and M. Hatano, *Bull. Chem. Soc. Jpn.*, **52**, 2678 (1979); **54**, 513 (1981).
11) K. Harata, *Bull. Chem. Soc. Jpn.*, **51**, 2727 (1978) and references cited therein Nos. 5, 6, 8, and 18.
12) A. Ueno, Y. Hino, and T. Osa, Manuscripts are now in preparation.
13) D. D. Perrin, W. L. F. Armarego, and D. R. Perrin, "Purification of Laboratory Chemicals," Pergamon Press, Oxford (1980), p. 86.
14) V. Zanker, *Z. Phys. Chem.*, **2**, 52 (1954).
15) B. C. Myhr and J. G. Foss, *Biopolymers*, **4**, 949 (1966).
16) D. F. Bradley and M. K. Wolf, *Proc. Natl. Acad. Sci., U. S.*, **45**, 944 (1959).
17) R. E. Ballard, A. J. McCaffery, and S. F. Mason, *Biopolymers*, **4**, 97 (1966).