Formation of Pyrene Excimer in an Association Dimer of Pyrene-appended γ-Cyclodextrin

Akihiko Ueno,* Iwao Suzuki, and Tetsuo Osa*
Pharmaceutical Institute, Tohoku University, Aobayama, Sendai 980, Japan

Pyrene-appended γ-cyclodextrin (**1**) forms an association dimer, in which excimer formation between two pyrene moieties occurs.

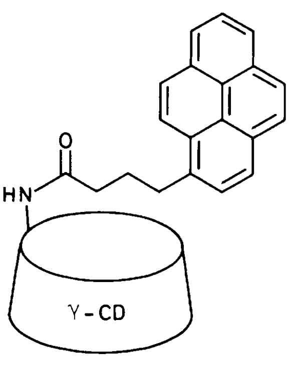
γ-Cyclodextrin, which is a cyclic oligosaccharide composed of eight α-1,4-linked D-glucopyranose residues, shows the unique property of including two molecules of naphthalene and its derivatives in its cavity.[1] This 1 : 2 host–guest complexation has mostly been studied by using fluorescence techniques since excimer emission from aromatic guests can provide direct evidence for their mutual interactions in the γ-cyclodextrin cavity. Since excimer emission of pyrene and its derivatives is also enhanced by γ-cyclodextrin, ternary complexes similar to those of naphthalene might be formed. However, inconsistent results were reported with regard to the stoicheiometry,[2—8] and it remains to be clarified whether the 1 : 2 (**A**) or 2 : 2 (**B**) complex is formed. In connection with this problem, we describe here results for the fluorescence of pyrene-appended γ-cyclodextrin (**1**), which suggest the stoicheiometry and geometrical features of complexation between pyrene and γ-cyclodextrin.

Compound (**1**) was prepared by reaction of dicyclohexylcarbodiimide (1.0 mmol), pyrene-1-butyric acid (0.9 mmol), and 6-deoxy-6-amino-γ-cyclodextrin (0.2 mmol) in *N*,*N*-dimethylformamide (DMF). Purification on a Sephadex LH-20 column with 35% aqueous DMF solution followed by the usual work-up afforded (**1**) as a powder (yield 18%).[†] Owing to the low solubility of (**1**) in pure water, spectral measurements were carried out for (**1**) dissolved in 10% aqueous dimethyl sulphoxide.

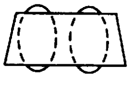
Fluorescence spectra of (**1**) exhibited excimer fluorescence with a maximum intensity at 470 nm in addition to monomer fluorescence with peaks at 379 and 397 nm. The excimer fluorescence intensity compared with that of monomer fluorescence increased markedly with increasing concentration of (**1**), suggesting that (**1**) tends to form an association dimer. The absorption of (**1**) was also dependent on concentration of (**1**), the peak at 344 nm decreasing with increasing

---

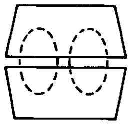
[†] R_f 0.56 (n-butanol/EtOH/water 5 : 4 : 3); fast atom bombardment (f.a.b.)-m.s.: *m/z* 1566 (M^+); Satisfactory elemental analysis and spectral data were obtained.



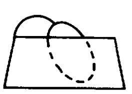
(1)



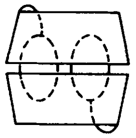
(A)



(B)



(C)



(D)

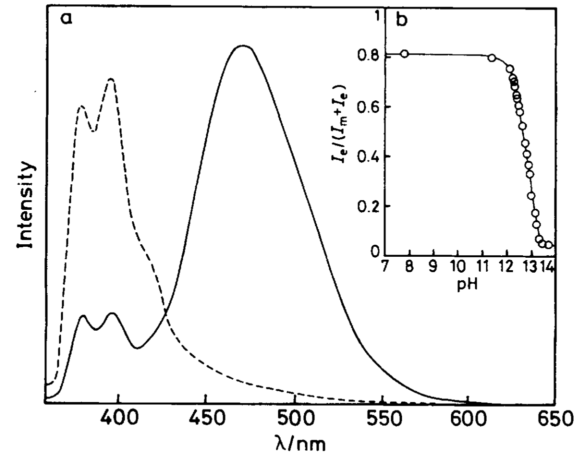


Figure 1. (a) Fluorescence spectra of (**1**) in an aqueous 10% dimethyl sulphoxide solution (2.85×10^{-5} M) at pH 11.3 (——) and 13.5 (---). The intensity ratio of excimer to total emission plotted against pH is shown in (b). I_e and I_m are fluorescence intensities at 470 and 397 nm, respectively; excitation wavelength 355 nm.

concentration of (**1**). The concentration-dependency of the absorbance was used to evaluate the association constant of (**1**) (K_D), which was determined to be 170 000 mol^{-1} dm^3 by curve-fitting analysis. The estimated absorption coefficients at 344 nm were 33 000 and 9 800 for the monomer and the association dimer, respectively. The c.d. spectrum of (**1**) measured at 25 °C exhibits a complicated pattern with peaks at 397, 365, and 312 nm and troughs at 349, 338, and 286 nm. However, it changed to a simple pattern with peaks at 343 and 326 nm and a trough at 276 nm when the temperature was raised to 80 °C. This spectral variation is caused by dissociation of the dimer into monomer species. The induced c.d. of the monomer species observed in the absorption region of pyrene indicates that the pyrene moiety is included in the γ-cyclodextrin cavity of the monomer, giving the intramolecular complexation form (**C**).

Upon addition of (−)-borneol or adamantane-1-carboxylic acid to the solution of (**1**), the excimer intensity ratio decreased and the pattern of u.v. absorption tended to become that of the monomer species. This result suggests that equilibria (i) and (ii) exist in this system. The association constants of the 1:1 host–guest complexation (K) were determined by analysis of guest-induced u.v. variations at 344 nm. The association constants were 2 200 and 3 050 mol^{-1} dm^3 for (−)-borneol and adamantane-1-carboxylic acid, respectively.

$$(\mathbf{1}) + (\mathbf{1}) \overset{K_D}{\rightleftharpoons} (\mathbf{1})_2 \qquad \text{(i)}$$

$$(\mathbf{1}) + \text{guest} \overset{K}{\rightleftharpoons} (\mathbf{1})\text{–guest} \qquad \text{(ii)}$$

When the pH of the solution of (**1**) was increased, the excimer emission was found to diminish abruptly at pH 12.7. Figure 1 shows typical fluorescence spectra below and above pH 12.7 together with the pH profile of intensity ratio of excimer to total emission, $I_e/(I_m + I_e)$, where I_m is the monomer intensity at 397 nm. The pH at which the transition occurs corresponds to the pK_a of the secondary hydroxy groups of cyclodextrins;[9] therefore the decrease in the excimer intensity caused by increasing pH may be related to the formation of anionic forms of the secondary hydroxy groups of (**1**). The original excimer-rich pattern was recovered by addition of HCl to the highly alkaline solution. This pH dependency suggests that the association dimer of (**1**) has structure (**D**) in which the secondary hydroxy group sides of (**1**) are facing each other and dissociated into two monomer species above pH 12.7 owing to the ionic repulsion between the two negatively charged faces. The c.d. spectrum of (**1**) at pH 13.6 exhibits a simple pattern of the monomer species. The association constants of 1:1 host–guest complexation were determined by analysis of c.d. variations at 277 nm, to be 1 800 and 0 mol^{-1} dm^3 for (−)-borneol and adamantane-1-carboxylic acid, respectively. The loss of binding ability of (**1**) for the latter guest can be explained in terms of ionic repulsion between the host and the guest.

Thus, we have shown that association dimer (**D**) is formed by dimerization of (**C**). In analogy with this system, similar complexes may be formed between native γ-cyclodextrin and pyrene or its derivatives by dimerization of 1:1 complexes.[8]

This research was supported partly by a Grant-in-Aid for Scientific Research from the Ministry of Education.

Received, 24th May 1988; Com. 8/02082E

References

1 A. Ueno, F. Moriwaki, T. Osa, F. Hamada, and K. Murai, *Tetrahedron*, 1987, **43**, 1571, and references therein.
2 A. Harada and S. Nozakura, *Polym. Bull.*, 1982, **8**, 141.
3 T. Yorozu, M. Hoshino, and M. Imamura, *J. Phys. Chem.*, 1982, **86**, 4426.
4 N. Kobayashi, R. Saito, Y. Hino, A. Ueno, and T. Osa, *J. Chem. Soc., Perkin Trans. 2*, 1983, 1031.
5 K. Kano, H. Matsumoto, S. Hashimoto, M. Sisido, and Y. Imanishi, *J. Am. Chem. Soc.*, 1985, **107**, 6117.
6 K. Kano, H. Matsumoto, Y. Yoshimura, and S. Hashimoto, *J. Am. Chem. Soc.*, 1988, **110**, 204.
7 W. G. Herkstroeter, P. A. Martic, and S. Farid, *J. Chem. Soc., Perkin Trans. 2*, 1984, 1453.
8 W. G. Herkstroeter, P. A. Martic, T. R. Evans, and S. Farid, *J. Am. Chem. Soc.*, 1986, **108**, 3275.
9 R. L. VanEtten, J. F. Sebastian, G. A. Clowes, and M. L. Bender, *J. Am. Chem. Soc.*, 1967, **89**, 3242.