One Host–Two Guests Complexation Between γ-Cyclodextrin and Sodium α-Naphthylacetate as shown by Excimer Fluorescence

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Summary The effect of increasing cyclodextrin (CD) concentration on the fluorescence spectra of sodium α-naphthylacetate is negligible for α-CD, large only in the normal fluorescence band for β-CD, and large for both the normal and the excimer fluorescence bands for γ-CD, showing the ability of γ-CD to form one host–two guests complexes.

Cyclodextrins (CD) contain six, seven, and eight glucose residues per molecule (α-, β-, and γ-CD, respectively). They have a lipophilic cavity with different inner diameters (4·5, 7·0, and 8·5 Å for α-, β-, and γ-CD, respectively) and form host–guest complexes with many molecules and ions.[1] The stoicheiometry of complex formation is usually 1 : 1 in aqueous solutions, but it is 2 : 1 for CD–large molecule complexes,[2,3] and for some others.[4] If the cavity is too large to fit one guest as is usually the case for γ-CD, one host-two guests complexes might be formed. We report here fluorescence evidence for one host–two guests complexation between γ-CD and sodium α-naphthylacetate (NA).

Many aromatic hydrocarbons and their derivatives show fluorescence of excited dimers (D*), produced by collisional interaction between excited and unexcited monomers: $M^* + M \rightarrow D^*$.[5] If two aromatic guests are included in the CD cavity, it seems probable such excimers may readily be formed. We have accordingly measured fluorescence spectra of NA in the presence of α-, β-, or γ-CD (25 °C; pH 8·7; Tris buffer). There have been many fluorescence-probe studies of the interaction of CD with aromatic guests,[1,6] but no study has been made relating to excimer fluorescence.

Solutions containing only NA at high concentrations exhibit a structureless band appearing at longer wavelength than the normal fluorescence. The band can be attributed to the excimer emission since the ratio of intensities of excimer to monomer fluorescence is proportional to the concentration of NA. The shapes of the fluorescence spectra of NA (10^{-2} mol l^{-1}) recorded at varying CD concentrations significantly depend on the type of CD (Figure). (i) Increase in α-CD concentration has no effect on either normal or excimer fluorescence. (ii) With β-CD, the intensity of the normal fluorescence increases with increasing β-CD concentration, the excimer band being unaffected. (iii) Both normal and excimer fluorescence intensities are markedly enhanced on increasing γ-CD concentration. Examination of molecular models suggests

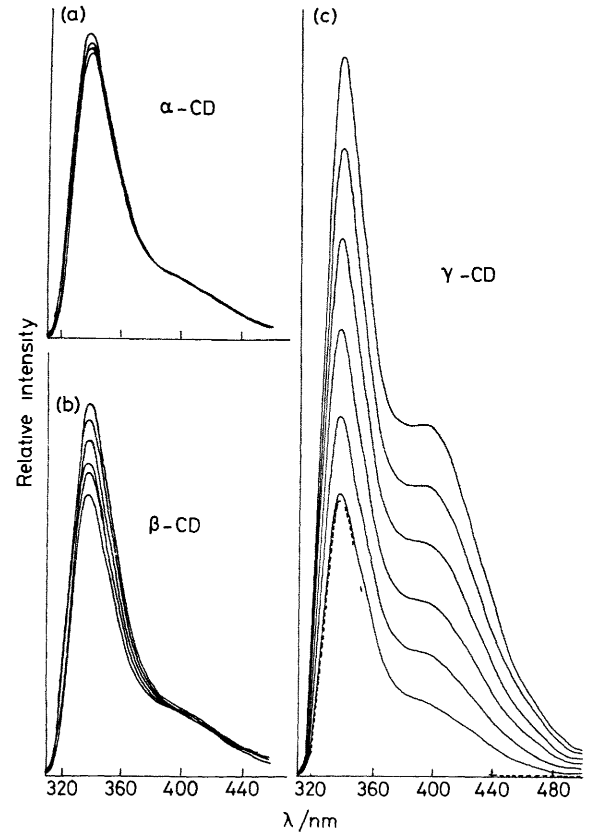

FIGURE Fluorescence spectra of sodium α-naphthylacetate (10^{-2} mol l^{-1}) in the presence of cyclodextrins (25 °C, pH 8 7, Tris buffer) The spectra, from top to bottom, correspond to varying concentrations of (a) α-CD, (b) β-CD, and (c) γ-CD as follows 10^{-2}, 8×10^{-3}, 6×10^{-3}, 4×10^{-3}, 2×10^{-3}, and 0 mol l^{-1} The broken line in (c) shows the normal fluorescence spectrum of a dilute solution of sodium α-naphthylacetate (10^{-4} mol l^{-1})

that the CD cavity is too small for α-CD, suitable for β-CD, and too large for γ-CD to accommodate one molecule of NA However, the large cavity of γ-CD is quite suitable for inclusion of two molecules of NA These experimental data may be interpreted as follows The observed insensitivity of the fluorescence to the variation in α-CD concentration indicates the inability of α-CD to include NA With β-CD, NA shows enhanced fluorescence which may be caused by a change in environment from the polar aqueous media to the lipophilic cavity on forming a 1:1 complex[7] The enhanced excimer formation in the presence of γ-CD may be explained in terms of a reaction between excited and ground-state NA monomers to produce a complex excimer, for example by the reactions in the Scheme The accompanying enhancement of normal fluorescence might be

$$\gamma\text{-CD}:(\text{NA})_2 + h\nu \leftarrow \gamma\text{-CD}:(\text{NA})_2^{*}$$
$$\uparrow$$
$$\gamma\text{-CD}:\text{NA} + \text{NA}^{*} \rightarrow \gamma\text{-CD}:(\text{NA}^{*}\cdot\text{NA})$$
$$\uparrow h\nu'$$
$$\gamma\text{-CD}:\text{NA} + \text{NA} \rightarrow \gamma\text{-CD}:(\text{NA})_2$$

SCHEME

attributed to the formation of a 1:1 complex, but this rationalization is inconsistent with the observation that a dilute solution of NA (10^{-4} mol l^{-1}) shows no enhancement despite the presence of γ-CD (10^{-2} mol l^{-1}) We therefore assume that the enhancement of normal fluorescence arises not from a 1:1 complex but instead from a 1:2 complex, γ-CD:(NA* NA), in which the excited monomer does not necessarily form an excimer, resulting in enhanced normal fluorescence

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[1] M L Bender and M Komiyama, 'Cyclodextrin Chemistry,' Springer-Verlag, Berlin, 1978
[2] H Schlenk and D M Sand, *J Am Chem Soc* , 1961, **83**, 2312
[3] F Vogtle and W M Muller, *Angew Chem* , *Int Ed Engl* , 1979, **18** 623
[4] A Ueno, H Yoshimura, R Saka, and T Osa, *J Am Chem Soc* , 1979, **101**, 2779, A Ueno, R Saka, and T Osa, *Chem Lett* , 1979, 841, 1007, 1980, 29
[5] J B Birks, 'Photophysics of Aromatic Molecules,' Wiley–Interscience, New York, 1964, p 301
[6] H E Edwards and J K Thomas, *Carbohydr Res* , 1978, **65**, 173
[7] K Harata and H Uedaira, *Bull Chem Soc Jpn* , 1975, **48**, 375