HETEROCYCLES, Vol. 6, No. 11, 1977

CYCLODEXTRIN-NITROPHENOL SYSTEMS STUDIED BY POLAROGRAPHY

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The effects of added α- and β-cyclodextrins on the half-wave potentials and the diffusion coefficients of o-, m-, and p-nitrophenols were examined, and a new polarographic method for determining the dissociation constants of cyclodextrin-substrate complexes was proposed. The dissociation constants of p-nitrophenol-cyclodextrin complexes obtained by polarographic method are in good agreement with those determined by spectrophotometric method. This polarographic method is applicable to many electroactive compound-cyclodextrin complexes whose dissociation constants can hardly be determined by spectrophotometric method.

Cyclodextrins which are cyclic 1,4-linked D-glucopyranose oligomers have characteristics of forming inclusion complexes with many organic compounds in an aqueous solution. The cyclodextrin complexes were studied in various fields because of their catalytic abilities as enzyme models. The driving forces for complex formation are van der Waals forces[1], hydrophobic interactions[2], and energetical stabilizations based on transformation from a strained high-energy tense conformation to an unstrained low-energy relaxed one[3]. Nitrophenols are also included in cyclodextrins and the dissociation constants of p-nitrophenol-cyclodextrin complexes were examined by spectrophotometric method[4,5]. It was, however, difficult to measure the dissociation constants of o- and m-nitrophenol-cyclodextrin complexes by spectrophotometric method because their spectra were almost unaffected by the addition of cyclodextrins. In this paper, we report the dissociation constants of o-, m-, and p-nitrophenol-cyclodextrin complexes determined by polarographic method[6]. Even in such systems where spectrophotometric method is impracticable, the polarographic method is applicable generally, if the included compounds are electroactive.

Table 1 shows that the half-wave potentials of nitrophenols are shifted to more negative side with increase in the concentration of cyclodextrins, which may be caused by the inclusion of nitrophenols in the basic atmosphere of cyclodextrins' cavities[7]. The half-wave potentials of both m- and p-nitrophenol are shifted to more negative side than that of o-nitrophenol, confirming that the former is more easily included in cyclodextrins than the latter.

From the Ilkovič equation, we obtained the following equation.

$$D_{ob} = \{i_d/(607nCm^{2/3}t^{1/6})\}^2 \qquad (1)$$

where D_{ob} is the observed diffusion coefficient, i_d is the average diffusion current, n is the number of electrons consumed by the electroactive substance, C is the concentration of the electroactive substance, m is the flow rate of the mercury, and t is the dropping time of the mercury. The observed diffusion coefficients for nitrophenols at various concentration of cyclodextrins are

Table 1. Half-Wave Potentials[a] of Nitrophenols in the Presence of Cyclodextrins. ($-E_{1/2}$ / V vs. SCE)

Conc. of α-CD[b] (M)	o-NP[c]	m-NP[c]	p-NP[c]
0	0.60	0.61	0.82
10^{-4}	0.67	0.69	0.84
10^{-3}	0.69	0.72	0.88
10^{-2}	0.68	0.73	0.96

Conc. of β-CD[b] (M)	o-NP[c]	m-NP[c]	p-NP[c]
0	0.60	0.61	0.82
10^{-4}	0.64	0.68	0.84
10^{-3}	0.67	0.70	0.87
10^{-2}	0.68	0.72	0.92

a; measured at 20°C in the phosphate buffer (pH 10.0); concentration of each nitrophenol, 10^{-4}M.

b; cyclodextrin. c; nitrophenol.

shown in Figure 1. These values decrease[8,9] with increase in the concentration of cyclodextrins. This is interpreted by the inclusion of small guest molecules in the large cyclodextrins. The extents of the decreases in the diffusion coefficients become more significant in the order of o-, m-, and p-nitrophenol. From these results, it is found that p-nitrophenol is more easily included in cyclodextrins than the others, and m-nitrophenol is more readily included in α-cyclodextrin than β-cyclodextrin. The decrease in

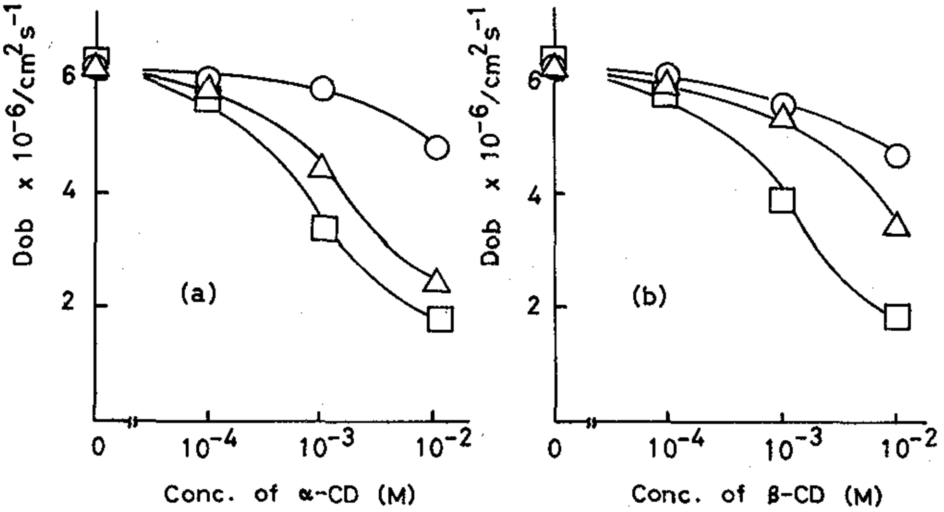

Fig. 1. The variations of the observed diffusion coefficients of nitrophenols in addition of cyclodextrins.
(a); α-cyclodextrin-nitrophenol complexes. (b); β-cyclodextrin-nitrophenol complexes.
○ ; o-nitrophenol-cyclodextrin complexes. △ ; m-nitrophenol-cyclodextrin complexes. □ ; p-nitrophenol-cyclodextrin complexes.

the observed diffusion coefficients is very small for o-nitrophenol. This observation suggests the presence of the steric effect unfavorable for complex formation derived from the closely situated nitro and phenolic hydroxyl groups.

As the dissociation and recombination rates of nitrophenol-cyclodextrin complexes are very fast[4,10], the observed diffusion coefficient can be written as

$$D_{ob} = D_{np} - x(D_{np}-D_{com}) \qquad (2)$$

where D_{np}, D_{com}, and x are the diffusion coefficient of nitrophenol in an aqueous solution, that of complex, and the fraction of complex formed[11]. When the concentration of cyclodextrin is excess to that of nitrophenol, the following equation is obtained.

$$D_{ob} = K_d(D_{np}-D_{ob})/[CD] \quad + \quad D_{com} \qquad (3)$$

where K_d and [CD] are the dissociation constant of complex and the concentration of cyclodextrin respectively. From the intercept of D_{ob} vs. $(D_{np}-D_{ob})/[CD]$ plots, we obtained D_{com} of p-nitrophenol-α-cyclodextrin complex, $1.6 \pm 0.2 \times 10^{-6}$ cm^2s^{-1}, and that of p-nitrophenol-β-cyclodextrin complex, $1.5 \pm 0.2 \times 10^{-6}$ cm^2s^{-1}. The present value of D_{com} for β-cyclodextrin complex is smaller than that for uncomplexed β-cyclodextrin measured by the Rayleigh interference method[12]. The slopes of these plots gave K_d of p-nitrophenol-α-cyclodextrin complex, $4.1 \pm 0.9 \times 10^{-4}$ M, and that of p-nitrophenol-β-cyclodextrin complex, $9.8 \pm 3.2 \times 10^{-4}$ M. These values are in good agreement with those determined by spectrophotometric method as shown in Table 2. For o- and m-nitrophenol, it is difficult to determine the dissociation constants of the complexes by spectrophotometric method, because the spectral change is small in forming complexes and also they can hardly be included in cyclodextrins even in a high concentration of cyclodextrins. we can, however, also obtain the dissociation constants of these complexes from eq. 2 on the basis of the reasonable assumption that the diffusion coefficients of p-nitrophenol-cyclodextrin complexes are equal to those of o- and m-nitrophenol-cyclodextrin complexes. Such simple assumption cannot be applied in spectrophotometric method, since the difference of the molar absorption coefficients for free and complexed guest molecules depends upon each system.

Table 2. Dissociation Constants of Nitrophenol-Cyclodextrin Complexes. (M)

	α-CD Complex	β-CD Complex
o-NP	$5.0 \times 10^{-3} <$ [a]	$2.8 \times 10^{-3} <$ [a]
m-NP	$2.0 \pm 0.5 \times 10^{-3}$ [a]	$6.8 \pm 2.0 \times 10^{-3}$ [a]
p-NP	$4.1 \pm 0.9 \times 10^{-4}$ [b]	$9.8 \pm 3.2 \times 10^{-4}$ [b]
p-NP	4.1×10^{-4} [c]	1.3×10^{-3} [c]

a; determined by eq. 2 using D_{com} values of p-nitrophenol-cyclodextrin complexes.

b; determined by D_{ob} vs. $(D_{np}-D_{ob})/[CD]$ plots.

c; determined by spectrophotometric method at 20°C in the phosphate buffer (pH 10.2).

This polarographic method is applicable to many electroactive compound-cyclodextrin systems whose dissociation constants are difficult to be measured by spectrophotometric method.

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Received, 26th July, 1977