CHEMISTRY LETTERS, pp. 1029-1032, 1993.

Evaluation of Association between Cyclodextrins and Various Inorganic Anions in Aqueous Solutions by ^{81}Br NMR Spectroscopy

Yuko YAMASHOJI, Manabu FUJIWARA,[†] Takayuki MATSUSHITA,[†]* and Minoru TANAKA
Department of Applied Chemistry, Faculty of Engineering, Osaka University, Yamadaoka, Suita, Osaka 565
† Department of Materials Chemistry, Faculty of Science and Technology, Ryukoku University, Seta, Otsu 520-21

The line-broadening of ^{81}Br NMR signals observed in the presence of CyDs was applied to evaluate their binding abilities toward inorganic anions in aqueous solutions. The apparent association constants of α-CyD with anions have been found to decrease in the order $SCN^- > ClO_4^- > I^- > NO_3^- > Br^- \fallingdotseq F^- > Cl^-$.

Cyclodextrins (CyDs), which are cyclic oligosaccharides composed of six, seven and eight (1-4)-linked α-D-glycopyranosyl residues, to be noted here as α-CyD, β-CyD, and γ-CyD, respectively, have been attracted wide spread interests, because these can form inclusion complexes with a variety of organic and inorganic compounds. However, the guest molecules studied mostly are organic compounds and there have been only a few papers on the complexation with inorganic anions. Recently, the association constants of anions with several CyDs in aqueous solution have been determined by various methods such as absorption spectra,[1)] electrochemical analysis,[2)] and ^{1}H NMR spectra.[3)] The regioisomers of CyDs modified with pyridinio groups have been reported to form 1 : 1 charge transfer complexes with ionrganic anions such as I^-, SCN^- and Br^- and to exhibit the maximum value (9×10^5 M^{-1}, 1 M = 1 mol dm^{-3}) of the association constant for the complexation of the hexapyridinio derivative of α-CyD with I^-.[4)]

On the other hand, the current development of multinuclear approach to NMR technique makes it possible to measure directly the behavior of halide ions, because the line widths of quadrupole nucleus are very sensitive to microenviroment of their neighborhood. For example, the interaction of water-soluble polymers with I$^-$ in aqueous solution has been investigated by ^{127}I NMR line-broadening technique.[5,6]

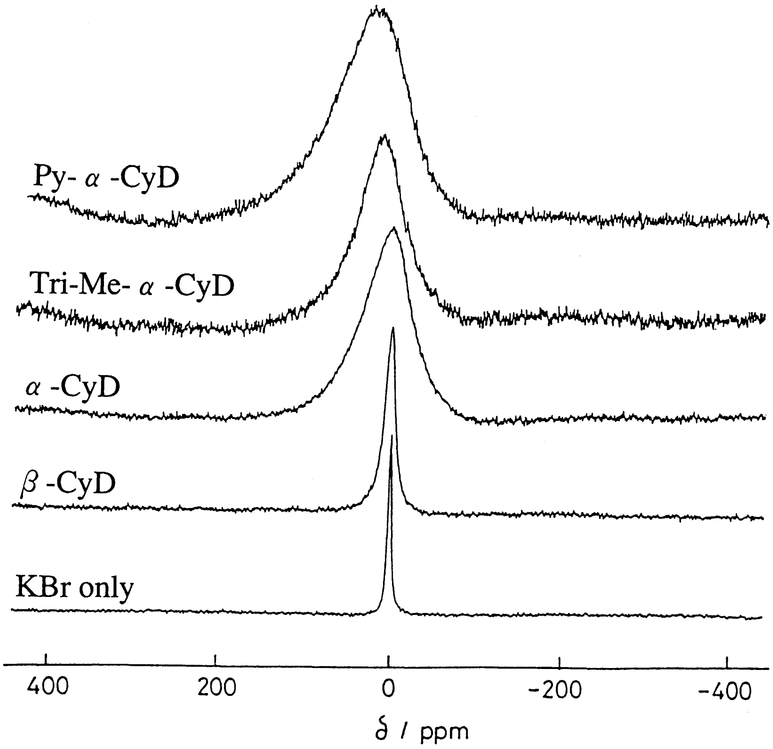

Fig. 1. ^{81}Br NMR spectra of KBr (0.2 M) aqueous solution with and without CyDs.

In this communication, we describe the evaluation of the association between various anions and several CyDs by measuring the line width of ^{81}Br NMR in aqueous solution. According to our limited knowledge, this is the first attempt, in which the ^{81}Br NMR technique has been applied to the complexation system of CyDs.

The NMR measurements were made on a JEOL JNM-GSX-400 spectrometer operating at 108 MHz for ^{81}Br nucleus. All of the NMR spectra were obtained with spinning and field locking by placing D_2O, in 5 mm tubes sealed under vacuum. The temperature was controlled at 298 K. In the ^{81}Br NMR experiments, 100 - 2500 FID were accumulated in a 65536 data point base over a 100 kHz spectral width for each solution prior to Fourier transformation. The line widths at half-height were obtained by magnifying repeatedly the peak on the picture. The errors in measuring a line width were estimated to be about ±5%. ^{81}Br NMR spectra were obtained from 50% D_2O aqueous solution containing 0.2 M KBr in the absence and presence of CyDs. The signal of ^{81}Br NMR exhibits a broad line width having a $\Delta\nu_{1/2}$ (line width at half-height) of 500 Hz. As shown in Fig. 1, the addition of CyDs to a KBr solution causes a small downfield shift of ^{81}Br NMR signal together with line-broadening. The line-width observed for the systems of α -CyD derivatives has been found to be generally broad in comparison with those of β-CyD. The excess line width was increased with an increase of the α-CyD concentration over the range of 0.01 - 0.05 M. Thus, all experiments were conducted under the concentration of α-CyD (0.05 M).

$$[\mathrm{CyD}]_{\mathrm{total}} \;/\; \triangle(1/T_2) = T_{2b} \;/\; K_{\mathrm{Br^-}} + T_{2b}\,[\mathrm{Br^-}]_{\mathrm{total}} \qquad (1)$$

Assuming that Br^- forms a 1 : 1 inclusion complex with α-CyD, the apparent association constant K_{Br-} can be calculated from the equation (1) proposed by J. D. Song *et. al.*,[6] where T_{2b} is the transverse relaxation time of CyD-bound Br^-, $\triangle(1/T_2)$ the excess relaxation rate, and $[Br^-]_{total}$ the total concentration of Br^- in the CyD solution. A plot of $[CyD]_{total} / \triangle(1/T_2)$ versus $[Br^-]_{total}$ gave a straight line with the slope T_{2b} and the intercept T_{2b} / K_{Br-}, from which the apparent association constant K_{Br-} was calculated to be 1.65 M^{-1}.

The excess line width of ^{81}Br NMR signal was found to decrease significantly from 5130 to 1460 Hz by adding 0.2 M KI. This phenomenon clearly indicates that α-CyD should interact with I^- stronger than Br^-, forming α-CyD-I^- complex by competition between both ions.

$$K_{\mathrm{Y^-}} / K_{\mathrm{Br^-}} = \{[\mathrm{CyD}]_{\mathrm{total}} / \triangle(1/T_2) - [\mathrm{CyD}]_{\mathrm{total}} / \triangle(1/T_2)_0\} \;/\; T_{2b}[\mathrm{Y^-}]_{\mathrm{total}} \qquad (2)$$

From the result of competition experiments, the apparent association constants of various anions are obtained using the equation (2), where K_{Y-} is the association constant of competing ion, $\triangle(1/T_2)_0$ the excess relaxation rate at $[Y^-]_{total} = 0$, and T_{2b} is obtained from eq. (1). The excess line widths of ^{81}Br NMR signal and the association constants of α-CyD with various anions obtained thus are summarized in Table 1. The value (12.4 M^{-1}) for the α-CyD-I^- system is comparable to

Table 1. Excess line widths of ^{81}Br NMR signals caused by the addition of various anions to the aqueous solution of KBr (0.2 M)-α-CyD (0.05 M) and the apparent association constants

Added salt / M		Excess line width / Hz	Association constant / M^{-1}
none		5130	1.65
KSCN	0.2	1070	18.7
$NaClO_4$	0.1	1890	16.9
KI [a)]	0.2	1460	12.4
KNO_3	0.2	3170	3.1
KF	0.2	3880	1.6
KCl	0.2	3930	1.5
K_2SO_4	0.2	4310	0.9

a) $Na_2S_2O_3$ (1 mM) was added for avoiding air oxidation.

those reported in the literature,[2)] which means that the present method is effective for the evaluation of association between the CyDs and anions. With ClO_4^-, $NaClO_4$ was used for poor solubility of $KClO_4$ in water, but it is known that the counter cation does not affect the interaction of CyDs with anions. The association constants of CyDs with anions have been found to decrease in the following order $SCN^- > ClO_4^- > I^- > NO_3^- > Br^- \fallingdotseq F^- > Cl^-$. This order is nearly in good agreement with the hydrophobic tendency.

As shown in Fig. 1, Py- α -CyD, which was obtained as a mixture of regioisomers randomly substituted with three pyridinio groups, induced the largest broadening of line width of ^{81}Br NMR signal among the CyDs investigated. The present results revealed that the complexation of the CyDs with the inorganic anions also depends on both their cavity size and electrostatic interaction. Thus, we are now in progress on the complexation between the modified CyDs having positively charged groups and various inorganic anions.

We would like to thank Mrs. Y. Miyaji at Faculty of Engineering, Osaka University for assistance in obtaining ^{81}Br NMR spectra.

References

1) Y. Matsui, M. Fujie, and K. Hanaoka, *Bull. Chem. Soc. Jpn.,* **62**, 1451(1989).

2) J. F. Wojeik and R. P. Rohrbach, *J. Phys. Chem.,* **79**, 2251(1975); R. I. Gelb, L. J. Schwartz, M. Radeos, and D. A. Laufer, *J. Phys. Chem.,* **87**, 3349(1983); P. Diard, E. Saint-Aman, and D. Serne, *J. Electroanal. Chem.,* **189**, 113(1985).

3) P. Mu, T. Okada, N. Iwami, and Y. Matsui, Preliminary results presented at 11th Cyclodextrin Symposium at Matue, 1992.

4) Y. Matsui, M. Fujie, and H. Sakate, *Bull. Chem. Soc. Jpn.,* **61**, 3409(1988); Y. Matsui, M. Fujie, and H. Sakate, *Carbohydr. Res.,* **192**, 91(1989).

5) S. H. Oh, R. Ryoo, and M. S. Jhon, *Macromolecules,* **23**, 1671(1990).

6) J. D. Song, R. Ryoo, and M. S. Jhon, *Macromolecules,* **24**, 1727(1991).

(Received March 4, 1993)