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Stability on Drying of Cyclodextrin Precipitates of Volatile Nonelectrolytes

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Cyclodextrins (CyD's) were precipitated in aqueous medium at 25 °C as inclusion complexes with twenty-two volatile nonelectrolytes (guests). The guest/CyD molar ratios of precipitates were measured immediately after preparation and after drying. Drying the precipitates for five hours at 50 °C under reduced pressure using a water-suction pump gave the same guest/CyD molar ratios as those obtained by drying in a desiccator over diphosphorus pentaoxide and stored there for two weeks. An iodine–α-CyD complex is quite stable on drying and, next to it are 1,2,3-trimethylbenzene–α-CyD and 1,2,4-trimethylbenzene–β-CyD complexes; other guest–CyD complexes are more or less unstable. The stability was found to be roughly correlated to the van der Waals volume of guest molecule(s) resident maximally in the CyD cavity.

Cyclodextrins (CyD's) are cyclic oligosaccharides with central cavities. The most widely used CyD's are α-, β-, and γ-CyD's, which are composed of six, seven, and eight glucopyranose units, respectively. The cavity size in the diameter, which somewhat differs from one publication to another, is in the range of 0.46–0.60 (α), 0.60–0.80 (β), and 0.80–1.0 nm (γ);[1] the cavity depth is about 0.7 nm, irrespectively of the type of CyD. The unique torus shape of the CyD allows appropriately shaped guest molecules to be included in the cavity. The inclusion complexes formed in aqueous medium precipitate, if the following two requirements are met. First, CyD in water should exceed a certain concentration characteristic of the host–guest combination. Second, the guest substance should possess very limited solubility in water and yet the guest molecules should be sufficiently supplied to water.

A shake-flask method has been used to prepare various CyD precipitates.[2,3] An alternative method, which we call vapor-circulation, has been proposed.[4] This method involves vaporization of a guest substance and continuous supply of the guest molecules to an aqueous CyD solution by circulating the guest vapor in a closed system. This method is superior to the shake-flask method with regard to the purity of precipitate obtained. The latter method needs, after separation of precipitates from the aqueous phase, removal of the excess liquid or solid guest substance by vaporization, sublimation, or washing with suitable organic solvents.

There are a number of studies concerning complex formation of CyD's with various guests in aqueous medium. Guest/CyD molar ratios of freshly prepared CyD precipitates of various volatile nonelectrolytes have also been reported.[2—5] Stability of dried CyD complexes, on the other hand, has received much less attention. It is interesting to know how the complexes lose their volatile guest molecules on exposure to air. To our knowledge, there have been reported two such studies. Leroy-Lechat et al. have studied preparations and stabilities of α-CyD complexes with iodine with a view to making iodine easier to handle and more applicable than its original crystals.[6] Schlenk and Sand have studied the stability of α- and β-CyD complexes with fatty acids after removing free (not included in CyD) fatty acids by evaporation; the complexes purified by evaporation are dried in a desiccator over P_2O_5 and then treated with heat and vacuum.[3] This study is concerned with volatilization losses of twenty-one hydrocarbons and iodine from CyD precipitates separated from water on drying or on storing, after drying, over a period of two weeks or one month in some instances.

Experimental

Reagents. All of the reagents used were of analytical reagent grade. Deionized distilled water was used throughout the experiments. α-, β-, and γ-CyD's of guaranteed grade (Nacalai Tesque Co.) were used as received.

Preparation of CyD Precipitates. The procedure to prepare CyD precipitates was described in a previous paper;[4] we call it the vapor-circulation method. By operating a Viton diaphragm airpump (Iwaki Co., AP-032Z), air saturated with a guest substance was bubbled in an aqueous CyD solution held at 25 °C and circulated in a closed system. The aqueous phase was then centrifuged at 4000 rpm to separate the CyD precipitate formed. In preparing iodine-included CyD precipitates, a method from the literature,[6] which we call the shake-flask method, was also used: iodine crystals were added to an aqueous CyD solution, the mixture was stirred for at least 24 h at 25 °C, then the CyD precipitate was separated together with iodine crystals from water through a sintered glass filter and washed with diethyl ether to remove iodine crystals.

Measurement of the CyD/Guest Ratio. CyD precipitates were treated and analyzed as described previously.[4] As an extractant, cyclohexane was used; when iodine and cyclohexane were used as guest substances, carbon tetrachloride and chloroform were used, respectively. Guest substances such as alkane, cyclohexane, and chloroform were analyzed with a Shimadzu GC-14B gas chromatograph (fused-silica wide bore capillary column of 0.53 mm×25 m, coated with poly(dimethylsiloxane)). The other hydrocarbons and iodine were analyzed with a Hitachi 100-50 spectrophotometer. A Shodex Model SE-11 differential refractometer (Showa Denko Co.) was used to measure CyD in the precipitates and in the supernatant aqueous solutions.

Drying and Preservation of CyD Precipitates. After centrifugation, one part of the CyD precipitate was immediately analyzed to measure the guest/CyD molar ratio and the other part was transferred onto a filter-paper and kept in a desiccator of about 8 dm^3 capacity over diphosphorus pentaoxide; the desiccator was placed in a room thermostated at 25±2 °C. After two or three days, the precipitate was pulverized, then one part was used for the molar ratio analysis and the other part was stored in the same desiccator for at longest one month (two months for iodine–α-CyD). During the storage, a part of the dried complex was taken out at a prescribed period and analyzed. The guest substances listed in Table 1 were thus dried and stored. Later, to shorten the drying and preservation time, CyD precipitates were treated, immediately after separation from aqueous solution, with a rotary vacuum evaporator (Tokyo Rikakikai Co., Type N-1). It was found that drying the freshly prepared CyD precipitates for five hours at 50 °C under reduced pressure by the use of a water-suction pump gave the same guest/CyD molar ratios for the guest substances given in Table 1. Preliminary experiments found that the molar ratio was almost independent of the evaporation time continued for 3 to 24 h.

Results and Discussion

Adsorption of Guest by CyD. A question may be raised whether the guest vapor generated in the course of dissociation of the CyD precipitate has some effects on the guest/CyD molar ratio during storage in the desiccator. We then examined the ability of CyD powder to adsorb guest substances under the saturated vapor of the guest substance; here, we studied three guest substances. In a desiccator (P_2O_5 was removed), CyD powders of three kinds were stored over the pure guest substance in sufficient amount and the desiccator was placed in the thermostated room (25±2 °C). The results, given in Table 2, show that the guest substance with high vapor pressure, such as benzene, affect the second significant figures of the guest/CyD molar ratio of the CyD precipitate. In fact, however, the vapor pressure of benzene generated from CyD precipitates of benzene is estimated to be one order of magnitude lower than the saturated benzene vapor pressure; the three kinds of CyD precipitates of benzene, each about 1 g, were stored in a single desiccator. The data listed in Table 2 show that, in a gaseous environment, guest molecules are not included in the CyD cavity, but adsorbed on the surface of CyD powder, because the guest/CyD molar ratio of each guest–host system is quite small even after a two-month contact with the saturated guest vapor and, moreover, selectivity is not observed for the guest–host system. Naphthalene and iodine molecules are found in α- and γ-CyD's, respectively, while these guest–host systems form no precipitation in aqueous medium. The presence of water seems to be essential for CyD inclusion complexations to occur.

Iodine as a Guest Substance. The iodine/CyD molar ratio of freshly prepared α-CyD precipitates by shake-flask and vapor-circulation methods was found to be 1.1; it was difficult to get three significant figures with the differential refractometer used in this work. More than ten assays were made on different samples prepared, changing the initial CyD concentration from (1.53 to 5.34)×10^{-3} M (1 M≡1 mol dm^{-3}). We were, however, not able to say with confidence that the molar ratio is 1.0. The molar ratio was reported to be 0.943±0.017 by Leroy-Lechat et al.;[6] iodine was measured by titrimetry, but CyD was not measured directly in their studies.

Table 1. Guest/CyD Molar Ratio of CyD Precipitate Determined after Keeping Precipitate in Desiccator over P_2O_5

Guest Substance[a)]	Type of CyD	Guest/CyD molar ratio			
		Days allowed to stand in desiccator			
		0	2 or 3	7	14(30)[b)]
(1)	α	1.1	0.65	0.23	0.23(0.23)
	β	1.1	0.51	0.04	0.05(0.04)
	γ	0.58	0.26	0.24	0.23(0.23)
(2)	α	0.59	0.46	0.46	0.46
	β	0.88	0.32	0.08	0.08(0.08)
	γ	0.76	0.58	0.41	0.38(0.38)
(3)	α	0.37	0.21	0.23	0.23
	β	0.65	0.45	0.17	0.17(0.17)
	γ	0.63	0.54	0.30	0.30(0.30)
(4)	α	1.1	0.51	0.51	0.51
	β	1.9	1.2	0.21	0.21(0.21)
	γ	2.7	0.47	0.06	0.06
(5)	α	1.1	0.68	0.51	0.51(0.51)
	β	1.9	0.14	0.10	0.10
	γ	3.0	0.76	0.23	0.23
(6)	α	0.90	0.70	0.54	0.54
	β	1.6	1.4	1.4	1.4
	γ	2.3	2.0	2.0	2.0
(8)	α	0.86	0.46	0.46	0.46
	β	1.5	0.27	0.26	0.26
	γ	2.2	1.2	0.79	0.79
(9)	α	0.92	0.24	0.21	0.21
	β	1.4	1.2	1.2	1.2
	γ	1.9	1.7	1.6	1.6
(10)	α	0.46	0.31	0.28	0.28
	β	1.4	0.75	0.75	0.75
	γ	1.9	1.6	1.5	1.5
(11)	α	0.46	0.34	0.31	0.31
	β	1.4	1.1	0.99	1.0
	γ	1.8	0.71	0.71	0.71
(12)	α	0.89	0.49	0.46	0.46
	β	1.3	0.72	0.72	0.72
	γ	2.1	1.2	1.2	1.2
(14)	α	0.32	0.24	0.24	0.24
	β	1.4	1.3	1.3	1.3
	γ	1.7	1.3	1.0	1.0
(22)	α	1.1	1.1	1.1	1.1[1.1]
	β	1.5	1.4	1.2	1.2(1.2)

a) The guest substance number corresponds to that shown in Table 3. b) The molar ratios determined after keeping CyD precipitates in desiccators for 30 and 60 d (one case, I_2-α) are designated in parentheses and brackets, respectively.

The iodine/CyD molar ratio of β-CyD precipitate has

Table 2. Guest/CyD Molar Ratio of CyD Determined after Keeping CyD Powder in Desiccator over Pure Guest Substance

Guest Substance[a)]	Type of CyD	Guest/CyD molar ratio			
		Days allowed to stand in desiccator			
		1	2	9	59
(4)	α	0.0033	0.0088	0.0038	0.010
	β	0.041	0.058	0.056	0.076
	γ	0.021	0.038	0.021	0.026
(18)	α	0.00074	0.00065	0.00056	0.00092
	β	0.0043	0.0045	0.0029	0.0083
	γ	0.0027	0.0034	0.0037	0.0071
(22)	α	0.00049	0.0020	0.0017	0.0022
	β	0.028	0.037	0.047	0.090
	γ	0.0081	0.0089	0.013	0.018

a) The guest substance number corresponds to that shown in Table 3.

not been reported in the literature. We prepared this precipitate at a high CyD concentration (9.67×10^{-3} M) by shake-flask and vapor-circulation methods, and an identical iodine/CyD molar ratio of 1.5 was obtained. An extremely prolonged vapor-circulation time was needed for precipitates prepared by the vapor-circulation method to reach a constant molar ratio. The iodine/CyD molar ratio found at a circulation time (indicated in the parentheses in h) were as follows: 0.6 (20), 1.1(40), 1.5(80), and 1.5(120). Neither the shake-flask nor the vapor-circulation method gave an I_2 precipitate with γ-CyD even at a high CyD concentration near its saturation in water.

Leroy–Lechat et al. have studied stability of the iodine-included α-CyD precipitate and reported that the 1 : 1 stoichiometry remains unchanged during storage at least 14 to 16 months. We also confirmed its stability, as shown in Table 1, though the storage period studied was only two months in our cases. For the β-CyD complex, on the other hand, the iodine/CyD molar ratio was found to decrease to 1.2 and to remain constant during at least one month when stored in a desiccator; this molar ratio was also observed after a continuous drying for 30 h at 50 °C using the rotary vacuum evaporator.

It is difficult to explain why the β-CyD complex with I_2 and α-, β-, and γ-CyD's complexes with hydrocarbons, which will be described below, are stabilized at a constant but fractional guest/CyD molar ratio. The structure and the state of the dried CyD complex must be closely related to its stability: The dried CyD complex exists in a solid solution as a nonstoichiometric compound or in two or more phases. We have no such information now.

Hydrocarbons as Guest Substances. The stability results are shown in Tables 1 and 3. Among the three CyD complexes with alkanes studied here, the β complexes are most unstable. The γ complexes are relatively stable, probably due to that an alkyl chain takes a helix-coil conformation in the cavity of γ to get contact as widely as possible with the cavity wall.[7,8] For α-CyD–heptane and –nonane, formation constants of 2 : 1 (CyD : guest) complexes in water are considerably larger than those of 1 : 1 complexes.[7] It has been suggested that, if the 2 : 1 formation constant is larger than or nearly equal to the 1 : 1 formation constant, the cross-section of secondary hydroxyl group sides of two CyD's are situated in parallel to each other at a suitable distance to form hydrogen bonds.[9] We assume that this situation is held in the solid state, too: two α molecules form a cage-like structure interposing one guest molecule. This is probably the case for *m*- and *p*-xylenes; *o*-xylene forms no 2 : 1 (CyD : guest) complex with α.[10]

Initial guest/CyD molar ratios of some α precipitates can thus be explained by taking into account the CyD–guest complex formation constants (association constants) in water. It is, however, difficult on the same basis to explain some other α precipitates. The 1 : 1 complex formation constant of α-CyD–1,3,5-trimethylbenzene is rather larger than that of α-CyD–(1,2,3- or 1,2,4-)trimethylbenzene.[10] Nevertheless, no precipitation of 1,3,5-isomer with α was observed. The solubility of guest substance in water is not directly concerned with whether precipitation occurs or not, because solubilities of these three isomers in water are almost identical.[11] It is necessary for CyD precipitation to occur that the associated complex formed in water should be hydrophobic as a whole, because CyD itself, especially α and γ, is rather hydrophilic; the solubility in water is 0.149 (α), 0.0163 (β), and 0.179 M (γ) at 25 °C. We have no information about the relationship between the hydrophobicity of associated CyD complex and the association constant.

The guest substances dealt with in this study are only sparingly soluble in water. Association constants of CyD with such guests have been measured in water under conditions in which the concentration of guest in water is lower than that of CyD. The data of the association constant thus measured, therefore, bear no relation to precipitation of β- and γ-CyD complexes with initial guest/CyD molar ratios larger than unity.

The number of guest molecules to be included in a single CyD cavity is, in general, larger for γ than β, because the former cavity size is larger. This is, however, not the case for 1,2,3-trimethylbenzene. As this was unexpected, we repeated the preparation and analysis of this guest–CyD (β and γ) complexes, and obtained the same result. This guest molecule(s) must protrude, to a large extent, from the cavity of β, since it is not large enough to accept three guest molecules together. This is probably responsible for the lower stability of this complex on drying, compared to β complexes with its isomers.

Relationship between Stability of Dried CyD Complex and Guest Molecular Volume. It seems

Table 3. Stability of Guest-Included CyD Precipitates Separated from Water

Guest substance	Type of CyD	Guest/CyD molar ratio of precipitate		Percent loss of guest[c)]	Molecular volume of guest[d)]
		Initial[a)]	Final[b)]	%	nm^3/molecule
(1) Pentane	α	1.1	0.23	79	0.0918
	β	1.1	0.04	96	
	γ	0.58	0.23	60	
(2) Heptane	α	0.59	0.46	22	0.124
	β	0.88	0.08	91	
	γ	0.76	0.38	50	
(3) Nonane	α	0.37	0.23	38	0.156
	β	0.65	0.17	74	
	γ	0.63	0.30	52	
(4) Benzene	α	1.1	0.51	54	0.0815
	β	1.9	0.21	89	
	γ	2.7	0.06	98	
(5) Fluorobenzene	α	1.1	0.51	54	0.0863
	β	1.9	0.10	95	
	γ	3.0	0.23	92	
(6) Iodobenzene	α	0.90	0.54	40	0.111
	β	1.6	1.4	13	
	γ	2.3	2.0	13	
(7) *p*-Dichlorobenzene	α	0.43	0.33	30	0.111
	β	1.4	0.83	43	
	γ	1.9	1.21	37	
(8) Toluene	α	0.86	0.46	47	0.0981
	β	1.5	0.26	83	
	γ	2.2	0.79	64	
(9) *o*-Xylene	α	0.92	0.21	77	0.111
	β	1.4	1.2	14	
	γ	1.9	1.6	16	
(10) *m*-Xylene	α	0.46	0.28	39	0.111
	β	1.4	0.75	46	
	γ	1.9	1.5	21	
(11) *p*-Xylene	α	0.46	0.31	33	0.111
	β	1.4	1.0	29	
	γ	1.8	0.71	61	
(12) Ethylbenzene	α	0.89	0.46	48	0.111
	β	1.3	0.72	45	
	γ	2.1	1.2	43	
(13) 1,2,3-Trimethylbenzene	α	0.39	0.36	7.7	0.127
	β	2.7	1.6	41	
	γ	2.0	1.7	15	

to be reasonable, from the standpoint of phase equilibrium, that the stability of CyD inclusion complexes, which are isolated from water, depends on the guest vapor pressure. We, however, have not studied the guest/CyD molar ratio as a function of the guest vapor pressure. As a measure of stability of a dried CyD complex, we take, as a matter of convenience, a percent loss of guest: 100×{(Initial guest/CyD molar ratio)−(Final guest/CyD molar ratio)}/(Initial guest/CyD molar ratio). The percent loss of guest is plotted in Fig. 1 against the guest molecular volume. The molecular volume used is the computer calculated intrinsic (van der Waals) value.[12)]

As abscissa, the original molecular volume is plotted, if the initial guest/CyD molar ratio is smaller than 1.2, while if the ratio is larger than 1.3, but smaller than 2.2 and if the ratio is larger than 2.3, two and three times the molecular volume are plotted, respectively. Taking experimental uncertainties into account, we cannot safely say that, if the guest/CyD molar ratio takes the value of 1.2, a part of another guest molecule exists together with one guest molecule in a single CyD cavity. In the same way, it cannot be safely said that, if the ratio is 2.2, a part of a third guest molecule is included in a single CyD. If, on the other hand, the ratio is larger than 1.3, but smaller than 2.2, or if the ratio is larger than 2.3, there is a possibility that the second guest molecule or the third guest molecule in the latter case, is included partly or fully in a single CyD cavity. In this sense, the value on the abscissa means the volume in the CyD cavity occupied maximally by the guest molecules(s).

Table 3. (Continued)

Guest substance	Type of CyD	Guest/CyD molar ratio of precipitate		Percent loss of guest[c)]	Molecular volume of guest[d)]
		Initial[a)]	Final[b)]	%	nm^3/molecule
(14) 1,2,4-Trimethylbenzene	α	0.32	0.24	25	0.127
	β	1.4	1.3	7.1	
	γ	1.7	1.0	41	
(15) 1,3,5-Trimethylbenzene	α	No precipitation			0.127
	β	1.5	1.2	20	
	γ	1.8	1.3	28	
(16) Propylbenzene	α	0.45	0.39	13	0.127
	β	1.4	1.1	21	
	γ	1.6	1.3	19	
(17) Isopropylbenzene	α	0.38	0.34	11	0.127
	β	1.4	0.89	36	
	γ	1.6	1.1	31	
(18) Naphthalene	β	1.3	0.70	46	0.125
	γ	1.9	1.6	16	
(19) Biphenyl	β	0.90	0.72	20	0.163
	γ	1.5	1.3	13	
(20) Cyclohexane	α	0.84	0.54	36	0.0993
	β	1.4	0.14	90	
	γ	2.2	0.66	70	
(21) Chloroform	α	1.2	<0.03	>98	0.134
	β	1.8	0.038	98	
	γ	2.7	0.033	99	
(22) Iodine	α	1.1	1.1	0	0.0892
	β	1.5	1.2	20	
	γ	No precipitation			

a) Initial ratio of precipitate was determined immediately after preparation of the precipitate. b) Final ratio was determined after evaporation drying for five hours at 50 °C under reduced pressure. c) Percent loss of guest was estimated by 100×{(Initial ratio)−(Final ratio)}/(Initial ratio). d) Taken from Ref. 11.

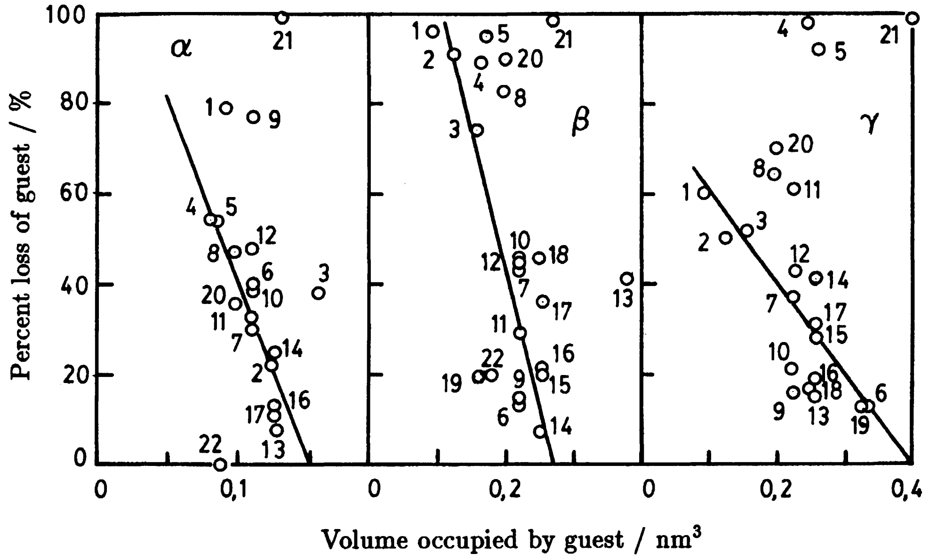

Fig. 1. Relationship between the percent loss of guest and the volume in CyD cavity occupied maximally by guest molecule(s). The number refers to the guest shown in Table 3.

The plots in Fig. 1 show large scatter, but a trend can be read. That is, the percent loss of guest seems to decrease as the volume occupied by the guest molecule(s) approaches to a certain point on the abscissa. We made bold to line in Fig. 1; the line intersects the abscissa at 0.15 (α), 0.27 (β), and 0.40 nm^3 (γ). It seems likely that a CyD complex is most stable, if the volume occupied by the guest molecule(s) just fits in the inside volume of a CyD molecule. This, however, does not hold for chloroform. Of guest substances used in

Table 4. Concentration of CyD in Supernatant Solution after Separation CyD Precipitates

Guest substance[a)]	Type of CyD	Initial concentration of CyD/M	Concentration of CyD in supernatant solution/M
(1)	α	1.49×10^{-2}	1.1×10^{-2}
	γ	1.00×10^{-2}	7.6×10^{-3}
(2)	α	2.27×10^{-2}	9.4×10^{-3}
	γ	2.02×10^{-2}	1.6×10^{-2}
(3)	α	1.20×10^{-2}	8.5×10^{-3}
	γ	2.05×10^{-2}	1.7×10^{-2}
(7)	α	3.00×10^{-2}	1.8×10^{-2}
	β	2.01×10^{-3}	1.9×10^{-4}
	γ	9.98×10^{-3}	9.3×10^{-4}
(8)	α	3.00×10^{-2}	1.6×10^{-2}
	β	2.02×10^{-3}	6.6×10^{-4}
	γ	1.00×10^{-2}	2.0×10^{-4}
(9)	α	5.01×10^{-2}	8.6×10^{-3}
	β	2.03×10^{-3}	2.2×10^{-4}
	γ	1.05×10^{-2}	8.8×10^{-5}
(10)	α	5.00×10^{-2}	2.8×10^{-2}
	β	2.02×10^{-3}	4.7×10^{-4}
	γ	8.15×10^{-3}	2.4×10^{-4}
(11)	α	3.00×10^{-2}	1.1×10^{-2}
	β	2.07×10^{-3}	2.2×10^{-4}
	γ	1.01×10^{-2}	5.9×10^{-4}
(12)	α	2.98×10^{-2}	1.5×10^{-2}
	β	2.03×10^{-3}	4.4×10^{-4}
	γ	1.00×10^{-2}	4.0×10^{-4}
(13)	α	3.00×10^{-2}	1.8×10^{-2}
	β	2.04×10^{-3}	4.8×10^{-4}
	γ	1.00×10^{-2}	1.2×10^{-4}
(14)	α	1.20×10^{-1}	7.5×10^{-2}
	β	2.02×10^{-3}	1.0×10^{-4}
	γ	1.00×10^{-2}	3.5×10^{-4}
(15)	α	1.40×10^{-1}	No precipitation
	β	1.50×10^{-2}	9.8×10^{-3}
	γ	9.99×10^{-3}	2.2×10^{-3}
(16)	α	3.00×10^{-2}	1.3×10^{-2}
	β	2.01×10^{-3}	2.5×10^{-4}
	γ	1.00×10^{-2}	7.4×10^{-4}
(17)	α	5.00×10^{-2}	3.3×10^{-2}
	β	2.01×10^{-3}	1.2×10^{-4}
	γ	1.00×10^{-2}	8.9×10^{-4}
(22)	α	5.34×10^{-3}	9.5×10^{-4}
	β	9.67×10^{-3}	2.8×10^{-3}
	γ	1.00×10^{-1}	No precipitation

a) The guest substance number corresponds to that shown in Table 3.

this work, chloroform is rather polar, and hence, there is a possibility that this guest molecules are precipitated by associating, at the entrance of CyD cavity, with its primary and/or secondary hydroxyl groups.

The molecular volume of iodine is considerably smaller than the inside volume of α, but this complex is nevertheless the most stable. The X-ray crystallographic study shows that iodine molecules are arranged in the iodine-included α-CyD crystal in herring-bone cage-type fashion, with four water molecules as space-filling mediators; the structure is held together by an intricate network of hydrogen bonds.[13)] This is probably responsible for the extremely stability of the complex.

CyD Concentration in Supernatant Aqueous Solution. One of the requirements for guest–CyD complexes formed in water to precipitate is that the CyD concentration in water should be larger than a certain level characteristic of the guest–CyD combination. In this sense and also in relation to the solubility of CyD precipitate in water, the CyD concentration in the supernatant aqueous solution after separating the precipitate is important data. Of the guest–CyD combinations studied in this work, the data except those reported in our previous paper,[4)] are listed in Table 4.

Using this data, one can estimate the yield of a CyD precipitate. For instance, about 0.4 g of pentane–α-CyD precipitate is obtained, if 100 cm^3 of α-CyD solution of 1.49×10^{-2} M is used. As we have noticed in our previous paper,[4)] there are no relationships between the CyD concentration in the supernatant solution and the solubility of guest substance in water or the 1 : 1 association constant of the guest–CyD.

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