Synthetic Photochemistry. XIII.[1] Chiroptical Retention for the Reported "*antara-antara*"-3,3-Sigmatropy of Bicyclo-[3.2.0]hepta-3,6-dien-2-ones

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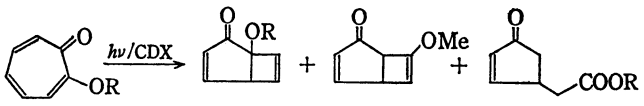
Troponoids were shown to form 2: 1-complexes with β-cyclodextrin and 1: 1-complexes with α-cyclodextrin. The photoisomerization of complexed tropolone and 2-methoxytropone gave optically active 1-hydroxy- and 1-methoxybicyclo[3.2.0]hepta-3,6-dien-2-ones in improved yields. The pyrolysis of the (+)-1-methoxybicyclo-[3.2.0]hepta-3,6-dien-2-one gave the (+)-3-methoxybicyclo[3.2.0]hepta-3,6-dien-2-one, ruling out the two-fold *supra-antara*-1,3-sigmatropy.

The utilizations of inclusion complexes for organic syntheses have been of interest,[2,3] but although there are many applications in various aspects including photolyses,[4] the photochemical valence-isomerization of guest molecules seems not to have been studied. We will herein describe the results of the photoisomerization of cyclodextrin (CDX)-complexed tropolone derivatives to give bicyclo[3.2.0]hepta-3,6-dien-2-ones, primary photoproducts, with improvements in the yields and in the rates of the reaction, For the large-scale preparation of bicyclo[3.2.0]heptadienones, the previous method, photoisomerization in solutions,[5,6] was inadequate.

When an aqueous solution of β-CDX was mixed with tropolone (**1**), colorless precipitates were formed immediately. According to the titrations, the precipitates, [**1**: β-CDX], were analyzed and found to contain 2 mol of **1** for a CDX unit. A similar type of 2: 1-complex was formed from 2-methoxytropone (**2**) and tropone (**3**). On the contrary, α-CDX was shown to form 1: 1-complexes with these troponoids.

The regeneration of troponoids from the complexes required a prolonged liquid-liquid extraction; a simple separatory extraction or solid-liquid (Soxlét) extraction was not effective.

By the external irradiation of [**1**: β-CDX] as a water dispersion, a known photoisomer of **1**, 1-hydroxybicyclo[3.2.0]hepta-3,6-dien-2-one (**4**),[6] was obtained in a 64% yield after the liquid-liquid extractions. As a minor product, 4-oxo-2-cyclopentenylacetic acid (**7**)[6] was also obtained. On the other hand, [**2**: β-CDX] and [**2**: α-CDX] were relatively soluble in water, and the photoreaction needed a prolonged time to give **5**, **6**, and **8**,[5] while in hexane the isomerization proceeded more efficiently. There is an apparent correlation between the solubility and the rate of the reaction; the less soluble the media, the greater the rate of the reaction. Figure 1 shows the comparative figures of this medium effect. It can also be noticed that, except for water, the rates of the reaction are not very different



1: R=H **4**: R=H **6** **7**: R=H
2: R=CH_3 **5**: R= CH_3 **8**: R=CH_3

Chart 1.

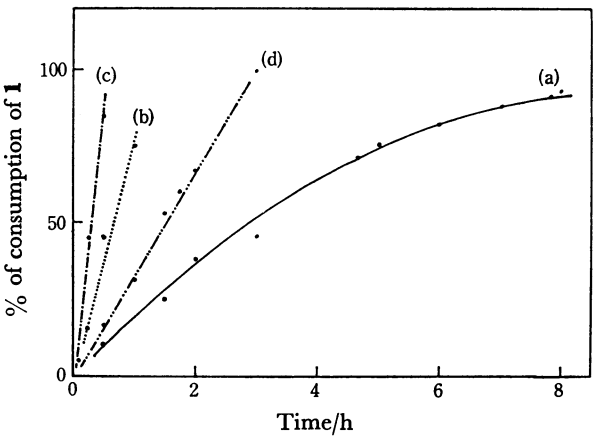


Fig. 1. Relative rates of photoreaction of **1** under various conditions. (a) in water without CDX, (b) in hexane without CDX, (c) as [**1**: α-CDX] in water, and (d) as [**1**: β-CDX] in water.

TABLE 1. THE PRODUCT DISTRIBUTIONS FOR THE PHOTOREACTION OF [**1**: CDX][a] IN VARIOUS SOLVENTS

Complexes	Media for dispersion	Isolated yields for **4**	Isolated yields for **7**
[**1**:α-CDX]	Water	68	21
	Methanol	65	15
	Acetone	58	10
	Hexane	66	20
[**1**:β-CDX]	Water	64	22
	Methanol	55	20
	Acetone	60	18
	Hexane	55	15

a) For each run, *ca.* 250 mg of **1** was used to prepare the complexes.

in various organic media, protic or aprotic; this is probably a reflection of a tight inclusion of troponoids in CDX. In the case of **2**, it is well known that the original product (**5**) was easily converted into the secondary photoproduct (**6**).[5]

These photoisomers were optically active; their ORD and CD curves are illustrated in Fig. 2, while some $[\alpha]_D^{20}$ values are shown in Table **2**.[7] The amplitudes of the optical rotation of the photoproducts obtained from [β-CDX] were larger than those obtained from

[α-CDX], and the amplitudes for the products of aprotic solvents were larger than those for protic solvents. Although we do not know the mechanism of this asymmetric reaction in detail, a host-guest interaction, *e.g.*, hydrogen bonding, may result in the geometrical fixation of troponoids in the asymmetric circumstance of the CDX molecules.[8] In this sense, it is interesting that the signs of the Cotton effect of **4** from **1** (proton-donor) and of **5** from **2** (proton-acceptor) are opposite. Furthermore, the opposite Cotton effects for **5** and **6** probably represents an inversion of asymmetric centers during the isomerization of **5** into **6**. This is in accord with the allowed 3*s*,3*s*-sigmatropy *via* the ketene intermediate (**B**), as has already been established.[9] The other path, the 1*s*,3*s*-process, retains the sign of the Cotton effect.

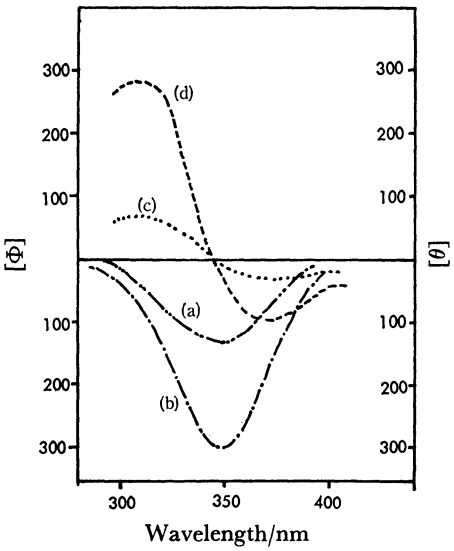


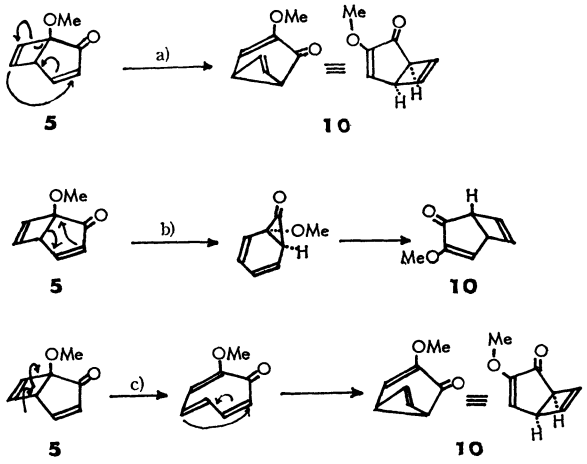
Fig. 2. The CD and ORD spectra of **4** obtained from [**1**: CDX]. (a) CD curve of **4** from [**1**: α-CDX] in water, (b) CD curve of **4** from [**1**: β-CDX] in water, (c) ORD curve of **4** from [**1**: α-CDX] in water, and ORD curve of **4** from [**1**: β-CDX] in water.

Table 2. The specific rotations of photoproducts

	$[\alpha]_D^{20}$(Concentration)	Irradiation conditions
4	−10.9°(*c*=1.15, MeOH)	(**1**: β-CDX) in H_2O
4	nil	(**1**: α-CDX) in H_2O
4	−9.8°(*c*=0.25, MeOH)	(**1**: α-CDX) in Hexane
5	+104°(*c*=0.24, MeOH)	(**2**: β-CDX) in H_2O
6	−22.7°(*c*=0.38, MeOH)	(**2**: α-CDX) in H_2O
6	−91.8°(*c*=0.24, MeOH)	(**2**: β-CDX) in H_2O

When a xylene solution of **4** was refluxed for 30 min, 3-hydroxybicyclo[3.2.0]hepta-3,6-dien-2-one (**9**) (25%) was obtained, together with **1** (25%). **9** has lost its optical activity. Even a brief heating at 110—115 °C for 5 min caused a complete racemization of the recovered **4** by means of a degenerated acyloin rearrangement.[10]

Then, an *o*-dichlorobenzene solution of **5** was refluxed for 3.5 h to give 3-methoxybicyclo[3.2.0]hepta-3,6-dien-2-one (**10**) (15%) as the sole isolable compound. **10** has retained its optical activity, with the same sign as the starting material, **5** (see Fig. 3).



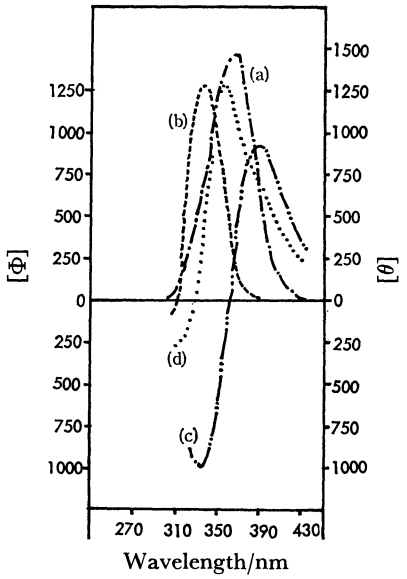


Fig. 3. The CD and ORD spectra of **5** and **10**. (a) CD curve of **5**, (b) CD curve of **10**, (c) ORD curve of **5**, and (d) ORD curve of **10**.

This type of rearrangement, **5** to **10**, was originally found by Mukai *et al.*[11] during the pylolysis of the 6-isopropyl derivative of **5**; at the sametime, the arrangement of the carbon atoms in the products was proved by using deuterio derivatives. Since then, this has been referred to as a unique example of a 3*a*,3*a*-sigmatropy (Route a)) in the literature,[12–15] but the mechanism of the reaction is still a point in dispute. Routes b), a two-fold 1*s*,3*a*-sigmatropy,[16] and c), an intermediary formation of a *cis-trans-cis*-triene (a *trans*-tropone),[17] which then suffers a thermal conrotatory cyclization,[18] have been alternatively suggested as plausible mechanisms. The differentiation of a), a concerted process, and c), a step-by-step process, may come from the view of the intermediate *trans*-tropone, and the present results alone can not provide information on such a point. However, the retention of the sign of the optical rotation for **10**

TABLE 3. CHARACTERIZATIONS OF CDX-COMPLEXES OF TROPONOIDS

Complexes	Yields/%	Ratio of tropones/host by UV spectrometry
[**1**: α-CDX]	85	0.85
[**1**: β-CDX]	83	1.80
[**2**: α-CDX]	45	0.87
[**2**: β-CDX]	65	1.91
[**3**: α-CDX]	75	0.76
[**3**: β-CDX]	68	1.66

clearly rules out Route b), by which chiroptically inverted **10** should be produced, as is shown in Chart 2. At the same time, any route involving a radical process,[15,16] which has been discarded on kinetical grounds,[12] can be conclusively eliminated.

According to Day *et al.*,[6] the formation of **7** can be diminished also by irradiation in aprotic solvents; however, this does not mean an improvement of the yields. In fact, a satisfactory yield of **4** was obtained only by the reaction in a very diluted solution; otherwise, a tarry, intractible mass was formed.

Experimental

Preparation of Inclusion Complexes (General Method). To an aqueous solution of CDX, two molar equivalents (for β-CDX) or one molar equivalent (for α-CDX) of troponoids, **1**, **2**, and **3**, were added. The precipitates thus formed were collected by filtration. The subsequent evaporation of the filtrate and washings of the residue with hexane yielded an additional amount of complexes.

The UV Titrations of the Troponoids–CDX Complexes. A constant weight of the CDX complexes of troponoids was dissolved in water and then determined by UV spectrometry. The results are summarized in Table 3.

Titrations of [1: CDX]. Aqueous solutions of [**1**: CDX] were diluted with constant volumes of 0.01 M (1M=1 mol dm^{-3}) KOH solutions and titrated by 0.01 M HCl. The results showed **1**/α-CDX=0.97 and **1**/β-CDX=1.82.

Photochemical Reaction of 1 as the Inclusion Complex with CDX. a): (General Method). A powdered complex of **1**, [**1**: β or α-CDX], was dispersed in a solvent (water, ethanol, hexane, or acetone) and irradiated by means of a 400-W high-pressure mercury lamp for several hours. Water was then added to the mixture, and it was continuously extracted with diethyl ether. The extracts were purified by silica gel chromatography; fractions eluted with benzene: diethyl ether (10: 1) afforded **4**, while subsequent fractions eluted with benzene: diethyl ether (5: 1) afforded **7**.

b): [**1**: β-CDX] (820 mg) was spread over an aluminum foil and externally irradiated by means of a 100-W high-pressure mercury lamp for 5 h. Continuous liquid-liquid extraction (diethyl ether: water) and subsequent silica gel chromatography of the extracts afforded **4** (23 mg, 36%), **7** (10 mg, 16%), recovered **1** (45 mg, 42%), and an unidentified oil (3 mg).

Photochemical Reaction of 1 in Hexane (Without CDX). a): A hexane solution (45 cm^3) of **1** (20 mg) was externally irradiated by means of a 100-W high-pressure mercury lamp for 10 h. Subsequent silica gel column chromatography of the mixture afforded **4** (8.3 mg, 42%), **7** (3.9 mg, 17%), and an unidentified oil (3 mg).

b): A hexane solution (45 cm^3) of **1** (120 mg) was similarly irradiated. The separation of the mixture gave **4** (6.7 mg, 5.6%) and **7** (2.5 mg, 1.7%).

Photochemical Reaction of 2 as the Inclusion Complex with β-CDX. a): A water (45 cm^3) suspension of [**2**: β-CDX] (300 mg) was externally irradiated by means of a 100-W high-pressure mercury lamp for 72 h. The reaction mixture was then continuously extracted with diethyl ether and chromatographed on a silica-gel column; from benzene, **6**, 13 mg (45%), and **5**, 7 mg (24%), were obtained, while from benzene: diethyl ether (10: 1), **8**, 3 mg (9%), was obtained together with the recovered **2**, 5 mg.

b): [**2**: β-CDX] (480 mg) was dispersed in hexane (50 cm^3) and then irradiated by means of a high-pressure mercury lamp for 24 h. The subsequent separation of the reaction mixture yielded **5** (19 mg, 30%), **6** (20 mg, 32%), and **8** (9 mg, 13%), together with the unreacted **2** (12 mg).

Pyrolysis of 4. Optically active **4** (48 mg) was dissolved in dimethyl sulfoxide (0.5 cm^3) and heated at 130—135 °C for 2 h. The NMR spectrum of the mixture indicated the presence of **9** and **1** in a ratio of 3: 2, but every attempt to isolate **9** failed; only **1** (15 mg, 31%) was obtained by silica-gel chromatography. The $[\alpha]_D^{20}$ value of the pyrolysate mixture was determined to be $\pm 0°$.

A Brief Heating of 4. **4** (15 mg) was dissolved in dimethyl sulfoxide (0.5 cm^3) and heated at 110—115 °C for 5 min, after which, the mixture was fractionated to isolate the recovered **4** (8 mg, 53%). The $[\alpha]_D^{20}$ value of the recovered **4** was $\pm 0°$. The CD spectrum showed no Cotton effect.

Pyrolysis of 5. **5** (20 mg) was dissolved in *o*-dichlorobenzene (3 cm^3) and refluxed for 3.5 h. The mixture was heated *in vacuo* to remove the solvent; the residue was then chromatographed on a silica-gel column to give oily **10** (3 mg, 15%) as the sole product.

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7) The CD and ORD spectra were recorded on a Jasco (Nippon Bunko Co.) ORD UV 5 Model provided by the courtesy of the Pharmaceutical School, Kyushu University.
8) When 2-chlorotropone and 2,7-dichlorotropone complexes of β-CDX were exposed to the UV light, a diminishment in the tropone chromophore was observed by UV spectrometry, but no product could be liberated by extractions. Probably, a condensation of CDX with active species derived from the halotropones took place during the irradiations.
9) O. L. Chapman and J. D. Lassila, *J. Am. Chem. Soc.*, **90**, 2449 (1968).
10) A sort of thermal acyloin rearrangement of the 1-hydroxybicyclo[3.2.*n*]alkan-2-one system was encountered during the endo-exo isomerization of the Diels-Alder adducts of maleic anhydride and **1**. See S. Itô, H. Takeshita, Y. Shoji, Y. Toyooka, and T. Nozoe, *Tetrahedron Lett.*, **1968**, 3215.
11) T. Miyashi, M. Nitta, and T. Mukai, *Tetrahedron Lett.*, **1968**, 3433.
12) Although Mukai's original paper[11] contained an

illustration suggesting the Process a), more detailed discussions have been provided in later papers (a) T. Miyashi, M. Nitta, and T. Mukai, *J. Am. Chem. Soc.*, **93**, 3441 (1971); b) R. Miyamoto and T. Mukai, *Nippon Kagaku Kaishi*, **1974**, 1691, where they have expressed reluctance to accept the concerted mechanism.

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