part of a joint program between CNRS (Laboratoire des Plantes Mêdicinales, Noumêa, New Caledonia) and the group of researchers in Naples. FAB and EI mass spectra were provided by the "Servizio di Spettrometria di massa" of the CNR and the University of Naples. The assistance of the staff is gratefully acknowledged. We are grateful to Professor F. Gasparrini, Faculty of Pharmacy, University of Rome, for FT IR measurements.

Registry No. 1 acid, 109152-31-0; 1a, 109152-37-6; 2 acid, 109152-32-1; 2a, 109152-38-7; 3 acid, 109152-33-2; 4 acid, 109152-34-3; 5 acid, 109152-35-4; 5a, 109152-39-8; 6 acid, 109152-36-5.

Modification of Photochemical Reactivity by Cyclodextrin. Difference in Photobehavior between Short Chain and Long Chain Benzoin Alkyl Ethers: Conformational Effect

G. Dasaratha Reddy and V. Ramamurthy*

Department of Organic Chemistry, Indian Institute of Science, Bangalore-560 012, India

Received January 15, 1987

The photochemical behavior of long chain benzoin alkyl ethers when complexed to β-cyclodextrin has been investigated with the view to understand their chemical behavior when included in the above host matrix. Photolysis results in benzil and pinacol ethers as the main products in solid β-cyclodextrin complex and benzaldehyde, benzil, pinacol ethers, and deoxybenzoin in aqueous β-cyclodextrin complex. The results on long chain benzoin alkyl ethers 4–6 are distinctly different from those of short chain benzoin alkyl ethers 1–3.

Introduction

A remarkable effect was recently reported on the photoreactivity of benzoin alkyl ethers[1] and alkyl deoxybenzoins[2] upon cyclodextrin complexation. Benzoin alkyl ethers are known to undergo Norrish type I reaction as the only photoprocess in organic solvents.[3] The competing type II hydrogen abstraction process, though feasible in these substrates, is not observed at all in organic solvents. Quite interestingly, the solid β-cyclodextrin complexes of substrates 1–3 (Scheme I) upon irradiation were found to yield only the type II products in quantitative yields.[1] The photolysis of aqueous solutions of the above complexes afforded a mixture of the type I and the type II products. The substantial difference in photoreactivity of benzoin alkyl ethers in β-cyclodextrin was attributed to a combination of the "cage effect" and "conformational control", afforded by the cyclodextrin cavity. The "cage effect" due to cyclodextrin has recently been established with several examples.[4] On the contrary, "conformational control" has not received due attention.[5] Therefore, in order to investigate the validity of proposing such a conformational control in cyclodextrin, the photobehavior of benzoin hexyl ether (4), benzoin octyl ether (5), and benzoin decyl ether (6) was investigated. We envisioned that by introducing longer alkyl chains in the alkoxy moiety, it should be possible to reverse the photobehavior as conformer B (Scheme II) would be populated to increasing extents as the longer alkyl chain on the alkoxy moiety would prefer to reside in the interior of the cyclodextrin cavity. In such a case, even in the presence of cage control there is no possibility of observing the type II reaction. results presented here confirm our prediction and provide support to our earlier postulate on the conformational control using cyclodextrin.[1] These results on benzoin alkyl ethers 4–6 when viewed in conjunction with the photobehavior of 1–3 clearly indicate that with carefully tailored molecules even crude binding sites such as those of the cyclodextrins are capable of profoundly influencing the conformations of included guests.[6]

Results

Photolysis of benzoin alkyl ethers 4–6 in N_2-saturated benzene solution and as a neat liquid resulted in the formation of benzaldehyde, benzil, pinacol ethers, and deoxybenzoin. While the first three products result from the Norrish type I α-cleavage process, deoxybenzoin arises from the intramolecular γ-hydrogen abstraction. Solution results on 4–6 are similar to the analogous systems reported in the literature.[3,7] The Norrish type I rearrangement product—*p*-benzoylbenzyl alkyl ether—was not obtained both in isotropic solvent and in cyclodextrin media. It is to be noted, however, that in micellar media such a product is obtained in major amount.[6] Results obtained upon photolysis of 4–6 in cyclodextrins (aqueous solution and solid state) along with those in benzene are summarized

---

(1) Dasaratha Reddy, G.; Usha, G.; Ramanathan, K. V.; Ramamurthy, V. *J. Org. Chem.* **1986**, *51*, 3085.

(2) Dasaratha Reddy, G.; Ramamurthy, V. *J. Org. Chem.*, in press.

(3) Lewis, F. D.; Lauterbach, R. L.; Heine, H. G.; Hartmann, W.; Rudolph, H. *J. Am. Chem. Soc.* **1975**, *97*, 1519. Adams, S.; Gusten, H.; Schulte-Frohlinde, D. Tetrahedron **1974**, *30*, 4249. Sander, M. R.; Osborn, C. L. *Tetrahedron Lett.* **1974**, 415. Heine, H. G. *Tetrahedron Lett.* **1972**, 4755. Pappas, S. P.; Chattopadhyay, A. *J. Am. Chem. Soc.* **1973**, *95*, 6484.

(4) Nageswer Rao, B.; Turro, N. J.; Ramamurthy, V. *J. Org. Chem.* **1986**, *51*, 460. Sharat, S.; Usha, G.; Tung, C. H.; Turro, N. J.; Ramamurthy, V. *J. Org. Chem.* **1986**, *51*, 941. Syamala, M. S.; Dasaratha Reddy, G.; Nageswer Rao, B.; Ramamurthy, V. *Curr. Sci.* **1986**, *55*, 875. Nageswer Rao, B.; Syamala, M. S.; Turro, N. J.; Ramamurthy, V. *J. Org. Chem.*, in press.

(5) For a few examples in which conformational effect has been invoked, see: Emert, J.; Kodal, D.; Catena, R. *J. Chem. Soc., Chem. Commun.* **1981**, 758. Turro, N. J.; Okubo, T.; Weed, G. C. *Photochem. Photobiol.* **1982**, *35*, 325. Arad-Yellin, R.; Eaton, D. F. *J. Phys. Chem.* **1983**, *87*, 5051. Vander Jagt, D. L.; Killiam, F. L.; Bender, M. L. *J. Am. Chem. Soc.* **1970**, *92*, 1016. Straub, T. S.; Bender, M. L. *J. Am. Chem. Soc.* **1972**, *94*, 8881. Griffiths, D. W.; Bender, M. L. *J. Am. Chem. Soc.* **1973**, *95*, 1679.

(6) Modification of the photobehavior of benzoin alkyl ethers through "conformational control" using micelles as reaction medium has recently been achieved in our laboratory. Ramamurthy, V. *Tetrahedron* **1986**, *42*, 5753. Devanathan, S.; Dasaratha Reddy, G.; Ramamurthy, V. In *Surfactants in Solution-Modern Aspects*; Mittal, K. L., Ed.; Plenum: New York, in press. Devanathan, S.; Ramamurthy, V., submitted for publication in *J. Org. Chem.*

(7) De Mayo, P.; Ramnath N. *Can. J. Chem.* **1986**, *64*, 1293. De Mayo, P.; Nakamura, A.; Tsang, P. W. K.; Wong, S. K. *J. Am. Chem. Soc.* **1982**, *104*, 6824.

0022-3263/87/1952-3952$01.50/0

Scheme I

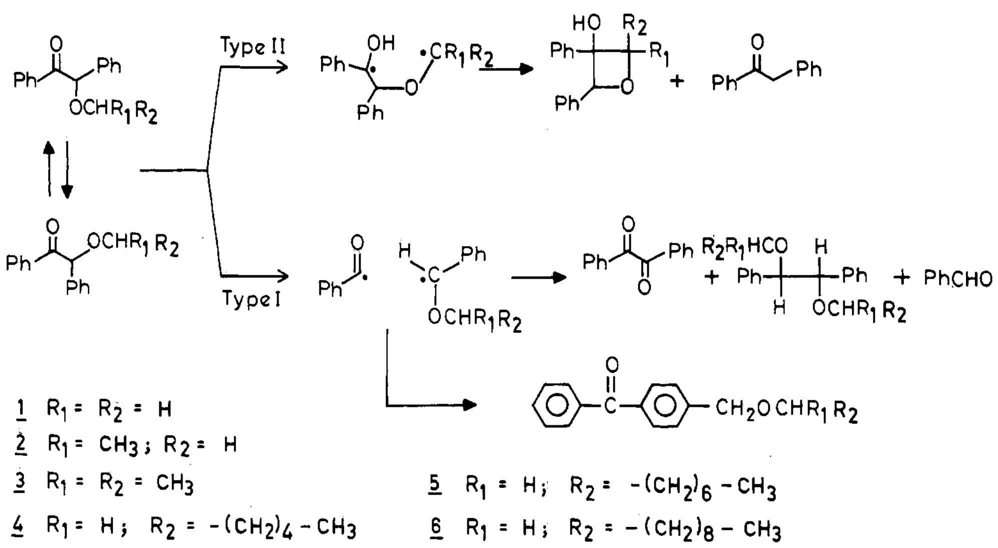


Table I. Product Distribution upon Photolysis of Benzoin Alkyl Ethers

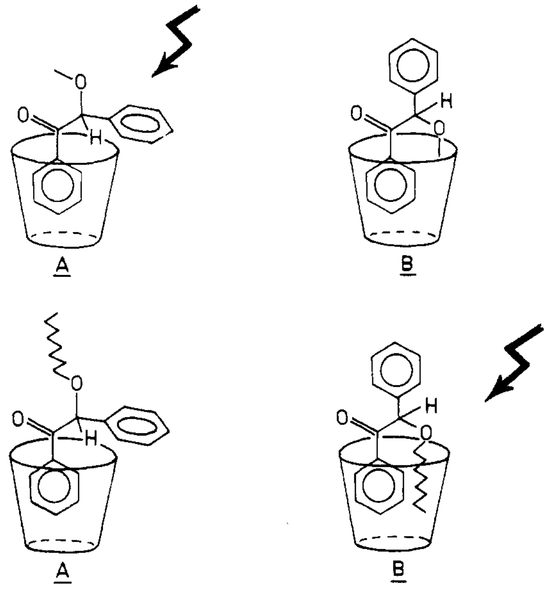
condition[g]	benzaldehyde, %	pinacol ether, %	benzil, %	deoxybenzoin, %
	Benzoin Methyl Ether[a]			
benzene	18	58	24	
β-cyclodextrin–solution (1:1)	23	54	7	16[e]
β-cyclodextrin–solution (5:1)	14	53	14	19[e]
β-cyclodextrin–solid (degassed)	8			92[e]
β-cyclodextrin–solid (O_2)				26[e,f]
	Benzoin Hexyl Ether[b]			
benzene	25	40	18	15
β-cyclodextrin–solution (1:1)	32	48	5	15
β-cyclodextrin–solution (5:1)	37	48	4	11
β-cyclodextrin–solution (degassed)	3	37	42	14
β-cyclodextrin–solid (O_2)	3	39	38	16
	Benzoin Octyl Ether[c]			
benzene	22	49	25	3
β-cyclodextrin–solution (1:1)	30	57	11	2
β-cyclodextrin–solution (5:1)	28	55	16	1
β-cyclodextrin–solid (deaerated)	3	51	45	1
β-cyclodextrin–solid (O_2)	3	52	44	1
	Benzoin Decyl Ether[d]			
benzene	40	45	14	2
β-cyclodextrin–solution (1:1)	42	52	2	4
β-cyclodextrin–solution (5:1)	42	55	2	1
β-cyclodextrin–solid (deaerated)	5	45	36	12
β-cyclodextrin–solid (O_2)	4	41	39	13

[a] $K_d = 6.0 \times 10^{-4}$ M L^{-1}; H/G ratio, 1:0.74. [b] $K_d = 3.0 \times 10^{-3}$ M L^{-1}; H/G, 1:0.87. [c] $K_d = 1.2 \times 10^{-3}$ M L^{-1}; H/G, 1:0.91. [d] $K_d = 4.0 \times 10^{-3}$ M L^{-1}; H/G, 1:0.93. [e] In this case the reported yield corresponds to the sum of deoxybenzoin and oxetanol. [f] The type I radicals were quenched by oxygen and gave benzoic acid and methyl benzoate as other products in 35% and 36%, respectively. [g] Solution refers to aqueous medium.

in Table I. The reported product yields are only relative and were estimated at 20% conversion of alkyl benzoin ethers. A plot of product distribution with respect to duration of irradiation did not show any variation in the ratio of products indicating that all the four photoproducts are stable under photolysis conditions at least up to ~20% conversion of **4**–**6**. For comparison the results on the photobehavior of benzoin methyl ether[1] are reproduced in Table I. It is important to note that the photolysis of benzoin methyl ether in cyclodextrin media provided a significant difference in behavior. However, the behavior of benzoin alkyl ethers **4**–**6** in aqueous solution when complexed to cyclodextrin was similar to that in isotropic solvent.

Most significant results were obtained upon irradiation of the solid cyclodextrin complexes. Under these conditions, in the case of benzoin methyl ether the type II products were obtained in near quantitative yields and products from the type I process were absent. On the other hand, **4**–**6** gave products resulting from the type I process in major amounts (Table I). Furthermore, while the photolysis of solid complexes of **1** is quenchable by oxygen, that of **4**–**6** is independent of the presence of oxygen. The result of immense significance to the present discussion is that the photobehavior of **4**–**6** is dramatically different from that of **1**–**3** when complexed to cyclodextrin, especially in the solid state. Unfortunately, the substrates **4**–**6** were liquids and thus did not allow a comparison of the product mixtures from the photolyses of complexed and uncomplexed substrates in the solid state. The fact that the inclusion of guest ketones **4**–**6** in cyclodextrin did not greatly alter their photobehavior with respect to the isotropic solvent is not unimportant and was indeed anticipated. The main focus, however, is on the relative behavior of these two sets of compounds, namely, short chain (**1**–**3**) and long chain (**4**–**6**) benzoin alkyl ethers.

Scheme II



The stability constants of the three complexes in aqueous solution were measured by the method of Benesi and Hildebrand,[8] and the values are provided in Table I. The X-ray powder photographs of the host and the complex were recorded and the difference between them revealed the formation of true complexes. The molar ratios of the solid complexes were 1:1, suggesting that one molecule of cyclodextrin includes only a single molecule of ketone.

Discussion

The photochemistry of benzoin alkyl ethers **1**–**3** is an example of the use of cyclodextrin to control the conformation of the guest molecule and thus alter the nature of the excited state chemistry. To provide an unequivocal proof for the proposed dramatic alteration in the conformation of the included guests **1**–**3**, X-ray crystallographic investigation of the single crystals of β-cyclodextrin–benzoin methyl ether inclusion complex was undertaken.[9] However, the structure solution was plagued by "disorder", characteristic of such inclusion complexes. In the absence of substantial progress in this approach, the results of **4**–**6** have been valuable. However, it is to be noted that direct evidence for the favored structure(s) is lacking.

Benzoin alkyl ethers **4**–**6** were chosen with the contention that they would prefer to complex with cyclodextrin in a conformation different from that of **1**–**3** (Scheme II). The alkyl benzoin ethers have three groups which can interact with the cyclodextrin cavity; the two phenyl rings and the hydrocarbon chain. We realize that only one phenyl ring can enter completely into the cavity of β-cyclodextrin and that there would be a competition between the second phenyl ring and the hydrocarbon chain for partial entry into the cavity. While in the case of **1**–**3**, the phenyl substituent would partially cover the cavity (Scheme II), the hydrocarbon chain would probably displace the second phenyl substituent from the cavity in **4**–**6**. This is because between the phenyl and the long chain alkyl groups, the latter being more hydrophobic, would prefer to reside in the cavity (along with another phenyl group) (Scheme II). The proposed preferred conformations for the short chain (**1**–**3**) and the long chain (**4**–**6**) benzoin alkyl ethers are illustrated in Scheme II. Results presented in Table I can indeed be interpreted on the basis of this model. Excitation of cyclodextrin complexes of **4**–**6** in the solid state gave mainly benzil and pinacol ethers, the coupling products of α-cleavage process. This is to be viewed in the light of the behavior of **1**–**3**, wherein the γ-hydrogen abstraction was the predominent process in the cyclodextrin cavity.

An examination of Scheme III reveals that of the two possible extreme conformations A and B, only A is capable of undergoing the type II process. Since the interconversion between A and B in the ground and in the excited states would severely be restricted in the solid complexes, the preferable complexation of **4**–**6** in the conformation B alone accounts for the photoreactivity of **4**–**6** in β-cyclodextrin cavity. Therefore, on the basis of the photobehavior of **4**–**6** we conjecture that long chain benzoin alkyl ethers while in the cyclodextrin cavity prefer a geometry in which one phenyl ring completely enters the cavity with the hydrocarbon chain partially covering the cavity. Although this model may have some shortcomings, at this stage it adequately provides an understanding for the difference in behavior between short chain and long chain benzoin alkyl ethers. However, unequivocal support through X-ray crystallographic studies is presently not available, as outlined above.

While formation of only a minor amount of the type II products was anticipated and supports our original model on "conformational control", the formation of benzil and pinacol ethers (type I products) in high yields was indeed surprising. The "cage effect" that operates in benzoin methyl ether **1** and other systems[4] is expected to play a role in this reaction too. As a consequence no net products are to be formed upon photolysis of complexes of **4**–**6**. The radicals originating from B (Scheme III) are expected to undergo geminate recombination, the diffusion of the radicals in the solid matrix being prohibited by the cage effect. Therefore, to account for the formation of the coupling products we invoke the possible presence of a 2:2 complex as illustrated in Scheme IV. Such structures have recently been proposed for complexes of several polyaromatics.[10] An X-ray crystal structure analysis of a cyclodextrin complex of a biphenyl derivative[11] indeed indicates such an arrangement.

In addition to a support from the literature, the observed results on product distribution in the presence of oxygen favors the proposed 2:2 complex. Oxygen has no effect during the photolysis of solid cyclodextrin complexes of **4**–**6**. This is to be analyzed in the light of the behavior of **1** wherein products obtained are benzoic acid and methyl benzoate (Table I)—the oxygen-trapped products of the type I benzoyl–benzyl radical pair. This difference can be attributed to several factors—intermolecular packing effect,[12] the presence of long hydrocarbon chain, which probably protects the chromophore by surrounding it, and the protection offered by the cavity in the structure of the type illustrated in Scheme IV. We only wish to point out that the absence of oxygen effect is not inconsistent with the proposed model.

The results presented here illustrate that two aspects of the molecular structure need to be considered while exploiting the host–guest complex for bringing about se-

---

[8] Benesi, H. A.; Hildebrand, J. H. *J. Am. Chem. Soc.* **1949**, *71*, 2703.

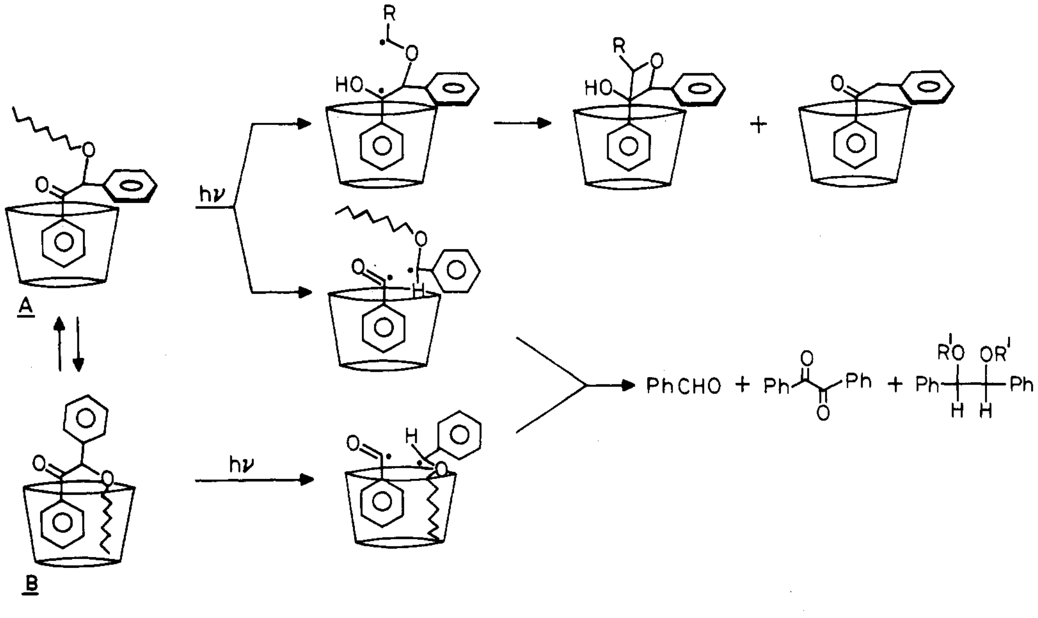
[9] Kanagapushpam, D.; Venkatesan, K.; Ramamurthy, V., submitted for publication in *Acta Crystallogr.*

[10] Herkstroeter, W. G.; Martic, P. A.; Evans, T. R.; Farid, S. *J. Am. Chem. Soc.* **1986**, *108*, 3275. Armstrong, D. W.; Nome, F.; Spiro, L. A.; Golden, T. D. *J. Am. Chem. Soc.* **1986**, *108*, 1418.

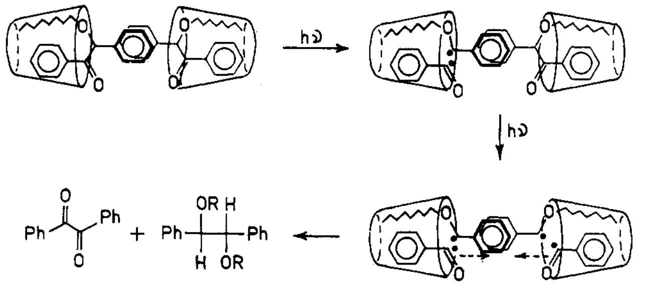
[11] Vekama, K.; Hirayama, F.; Imai, T.; Otagiri, M.; Harata, K. *Chem. Pharm. Bull.* **1983**, *31*, 3363.

[12] Arjunan, P.; Ramamurthy, V.; Venkatesan, K. *J. Org. Chem.* **1984**, *49*, 1765.

Scheme III



Scheme IV



lective transformations. The "intraguest" arrangement and intermolecular packing control the chemical behavior of the guest molecule.[13] Our intuitive approach that one could alter the course of the excited behavior of benzoin alkyl ethers by engineering them to adopt a suitable conformation has been realized. We wish to point out that the present results provide some support to "crystal engineering" approach to host–guest chemistry. However, unequivocal evidence regarding the structure is required before this approach can become useful and general.

Experimental Section

β-Cyclodextrin obtained from Aldrich was used as received. Benzoin alkyl ethers **4–6** were prepared following a reported procedure[14] and purified by column chromatography (silica gel, 15% chloroform in hexane). All the compounds were more than 98% pure according to analytical GLC and had the following spectral properties (IR and ^{1}H NMR) and analytical data.

4. IR (neat): 2900, 1670, 1600 cm^{-1}. ^{1}H NMR (CDCl$_3$): δ 0.9 (3 H, t); 1.0–1.8 (br s); 3.5 (2 H, t, J = 9 Hz); 5.35 (1 H, s); 7.20–7.60 (8 H, m); 7.9–8.1 (2 H, m). Anal. Obsd: C, 81.32; H, 8.35. Calcd: C, 81.04; H, 8.16.

5. IR (neat): 2900, 1670, 1600 cm^{-1}. ^{1}H NMR (CDCl$_3$): δ 0.90 (3 H, t); 1.0–1.80 (12 H, br s); 3.5 (2 H, t, J = 9 Hz); 5.35 (1 H, s); 7.2–7.6 (8 H, m); 7.9–8.1 (2 H, m). Anal. Obsd: C, 81.55; H, 8.90. Calcd: C, 81.44; H, 8.70.

6. IR (neat): 2900, 1670, 1600 cm^{-1}. ^{1}H NMR (CDCl$_3$): δ 0.90 (3 H, t); 1.0–1.6 (16 H, br s); 3.5 (2 H, t, J = 9 Hz); 5.35 (1 H, s); 7.20–7.60 (8 H, m); 7.90–8.1 (2 H, m). Anal. Obsd: C, 81.60; H, 9.42. Calcd: C, 81.77; H, 9.15.

Distilled solvents and doubly distilled water were used for all the experiments. ^{1}H NMR spectra were recorded on a Bruker WH 270-MHz NMR spectrometer. Powder diffractograms were recorded with a Phillips X-ray powder diffractometer equipped with Cu K$_\alpha$ radiation. Vapor chromatographic analyses were done on a Chemito gas chromatograph (Model 3800) fitted with a 5% SE-30 (on Chromosorb P) column (5 ft × $^1/_8$ in.). Absorption spectra were recorded with a Shimadzu UV 180 spectrometer.

Preparation of β-Cyclodextrin Complexes. To a saturated solution of β-cyclodextrin in distilled water (10 mL) equimolar amounts of ketones **4–6** were added and stirred for 24 h. The white microcrystalline precipitate was collected by filtration, washed with ether, and dried at 50 °C for 10 h. The aqueous solutions of the complexes were prepared by dissolving the microcrystalline complexes (100 mg) in 100 mL of distilled water for solution irradiations, and the microcrystalline material was used as such for solid irradiations.

Identification of the Complexes. Solid Complexes. The X-ray powder diffractograms of β-cyclodextrin and the complexes of β-cyclodextrin with **4–6** were recorded. The guest ketones were liquids. As the powder patterns of the complexes were different from that of β-cyclodextrin, it was concluded that inclusion complexes were formed between β-cyclodextrin and benzoin alkyl ethers **4–6**.

Measurement of Dissociation Constants (K_d). A stock solution of β-cyclodextrin (1.074 × 10^{-2} M) was prepared by dissolving 610 mg of β-cyclodextrin in 50 mL of distilled water. Solutions (10 mL) containing varying amounts of β-cyclodextrin stock solution (the final concentration of β-cyclodextrin varied between 10^{-4} and 10^{-2} M) and a constant amount of ketone (10^{-6} M) were prepared in standard flasks and stirred well. UV absorption spectra of these solutions were recorded and optical densities at 240 nm for **5** and 250 nm for **4** and **6** were monitored. A plot of ($a_0b_0/\Delta_{\rm OD}$) vs. ($a_0 + b_0$) was linear with the slope and intercept being equal to $1/\Delta\epsilon$ and $K_d/\Delta\epsilon$, respectively (a_0 and b_0 are the initial concentrations of β-cyclodextrin and ketone, respectively). The dissociation constants calculated for the ketones **4–6** are listed in Table I.

Photolysis of Cyclodextrin Complexes. The aqueous solutions of the complexes contained in Pyrex tubes prepared by dissolving the microcrystalline complex (100 mg) in 100 mL of distilled water were irradiated (300 ± 20 nm), after being purged with nitrogen gas for 45 min, on a Rayonet reactor fitted with RPR-3000 lamps. After the irradiation (1 h) the products were extracted from aqueous solution with warm chloroform. Photolysis of microcrystalline samples were carried out with a Hanovia 450-W

---

[13] Since the inclusion complexes are generally prepared in aqueous solution, the "hydrophobic effect" would be expected to play an important role in the "intraguest" arrangement. The molecular packing of the host–guest complexes in the solid state would be controlled by a large number of weak forces. For a review, see: Ramamurthy, V.; Venkatesan, K. *Chem. Rev.* **1987**, *87*, 433.

[14] Fischer, E. *Chem. Ber.* **1893**, *26*, 2412.

medium-pressure mercury lamp with Pyrex filters (>280 nm). Microcrystalline samples were degassed, sealed, and irradiated for 48 h in Pyrex tubes. In order to obtain a uniform exposure to light the sample tubes were rotated periodically. The conversions both in solution and in solid-state irradiations were less than 20%. Under such conditions the photoproducts were stable as analyzed by GLC. The products were extracted with a chloroform–water mixture and gas chromatographically analyzed. Among the photoproducts benzaldehyde, benzil, and deoxybenzoin were identified by comparison with authentic samples (Aldrich), and the other product pinacol ether was characterized by its spectral properties (IR and ^{1}H NMR) and compared with those pinacol ethers isolated from **1**–**3**. The IR and ^{1}H NMR spectra of diastereomeric pinacol ethers derived from **4**–**6** are provided here.

4. IR (neat): 2900, 1600, 1340 cm^{-1}. ^{1}H NMR (CDCl$_3$): (a) δ 0.95 (6 H, t); 1.0–1.60 (8 H, m); 3.20 (4 H, m); 4.05 (2 H, s); 6.80–7.20 (10 H, m); (b) δ 0.95 (6 H, t); 1.01–1.60 (8 H, m), 3.20 (4 H, m); 4.25 (2 H, s); 6.80–7.20 (10 H, m).

5. IR (neat): 2900, 1600, 1345 cm^{-1}. ^{1}H NMR (CDCl$_3$): (a) δ 0.95 (6 H, t); 1.0–1.65 (12 H, m); 3.20 (4 H, m); 4.05 (2 H, s); 6.9–7.20 (10 H, m); (b) δ 0.95 (6 H, t); 1.0–1.70 (12 H, m); 3.0–3.25 (4 H, m); 4.05 (2 H, s); 7.0–7.25 (10 H, m).

6. IR (neat): 2900, 1600, 1340 cm^{-1}. ^{1}H NMR (CDCl$_3$): (a) δ 0.90 (6 H, t); 1.0–1.70 (16 H, m); 3.0–3.25 (4 H, m); 4.05 (2 H, s); 7.0–7.20 (10 H, m); (b) δ 0.90 (6 H, t); 1.0–1.70 (16 H, m); 3.03–3.30 (4 H, m); 4.25 (2 H, s); 7.0–7.20 (10 H, m).

Photolysis (>280 nm) of the ketones **4**–**6** in benzene and methanol were also carried out. The irradiations (1 h) were done in NMR tubes with the initial ketone concentrations of ~1.6 × 10^{-2} M. The samples were analyzed by GLC.

Host/Guest Ratio. Known amounts of β-cyclodextrin complexes of the ketones **4**–**6** were dried to a constant weight after being washed with cold water and diethyl ether. The guest ketones were extracted with a warm chloroform–water mixture. From the amount of the ketone recovered and the total complex taken the host/guest ratio was calculated. The amount of the extracted ketone was also estimated by GC analysis using an internal standard (benzoin methyl ether). The two values thus obtained are in good agreement. The measured host/guest ratios for all the three β-cyclodextrin complexes are provided in Table I.

Acknowledgment. G.D.R. thanks Council of Scientific and Industrial Research, Government of India, for the award of Senior Research Fellowship.

Registry No. **1**, 3524-62-7; **1**·β-cyclodextrin, 102979-45-3; **4**, 22510-13-0; **4**·β-cyclodextrin, 109391-46-0; **5**, 36945-04-7; **5**·β-cyclodextrin, 109391-47-1; **6**, 38482-89-2; **6**·β-cyclodextrin, 109391-48-2; PhCHO, 100-52-7; (PhCH(OMe))$_2$, 3962-43-4; PhCOCOPh, 134-81-6; PhCH$_2$COPh, 451-40-1; PhCO$_2$H, 65-85-0; PhCO$_2$Me, 93-58-3; (Me(CH$_2$)$_5$OCH(Ph))$_2$, 109391-43-7; (Me(CH$_2$)$_7$OCH(Ph))$_2$, 109391-44-8; (Me(CH$_2$)$_9$OCH(Ph))$_2$, 109391-45-9; oxetanol, 92549-02-5.

Copper-Catalyzed Double Cyclization Reaction of Azidoquinones: One-Step Synthesis of Dihydropyrroloindoloquinones and Related Quinolinoquinones

Yoshinori Naruta,* Naoshi Nagai, Yoshihiro Arita, and Kazuhiro Maruyama*

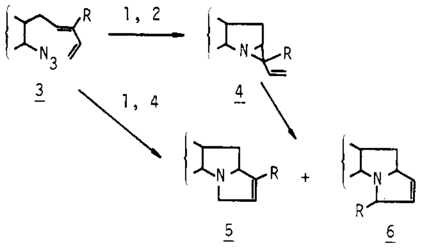
Department of Chemistry, Faculty of Science, Kyoto University, Kyoto, 606 Japan

Received March 2, 1987

Intramolecular cyclization of 2-azido-3-(2,4-pentadienyl)-1,4-quinone (**7**) has been examined in the presence of metal catalysts ML$_n$ (L = acetylacetonato). Copper or Cu(acac)$_2$ catalysts exhibited the highest catalytic activity both to the decomposition of the azide and to the formation of the corresponding dihydropyrroloindoloquinone (**8**), which was obtained in 58% yield in one step. The related 2-azido-3-(3,5-hexadienyl)-1,4-quinones gave the corresponding quinolinoquinone derivatives in moderate yields. The double cyclization reaction proceeds in extremely high regio- and stereoselectivities, and the generality was established. Quinonoid structure and the presence of a conjugated dienyl side chain at the proximal position to an azide group are essential factors for the completion of this double cyclization reaction. The role of the copper catalyst to the cyclization reaction is also discussed.

Cycloaddition reactions of organic azides or nitrenes to an unsaturated double bond have been studied directed toward the synthesis of nitrogen heterocycles,[1] such as aziridines,[2] pyrroles,[3] indoloquinones,[4] etc.[5] Decomposition of organic azides have been performed under pyrolytic,[3,5a–f] photolytic,[2a,4,5q] and acidic[6] conditions. By

Scheme I



---

(1) For reviews, see: (a) Abramovitch, R. A.; Kyba, E. P. *The Chemistry of the Azide Group*; Patai, S., Ed.; Wiley: London, 1971; pp 221–329. (b) Supplement D of ref 1a, 1983; Chapters 7 and 8. (c) Lewis, F. D.; Saunders, W. H., Jr. *Nitrenes*; Lwowski, W., Ed.; Wiley: New York, 1970. (d) Wentrup, C. *Adv. Heterocycl. Chem.* **1981**, *28*, 231. (e) Scriven, E. F. V., *Reactive Intermediates*; Abramovitch, R. A., Ed.; Plenum: New York, 1982; Vol. 2, pp 1–54. (f) *Azides and Nitrenes, Reactivity and Utility*; Scriven, E. F. V., Ed.; Academic: New York, 1984.

(2) (a) Scheiner, P. *Tetrahedron* **1968**, *24*, 2757. (b) Hassner, A.; Matthews, G. J.; Fowler, F. W. *J. Am. Chem. Soc.* **1969**, *91*, 5046. (c) Ende, D. V.; Krief, A. *Angew. Chem., Int. Ed. Engl.* **1974**, *13*, 279. (d) Ittah, Y.; Sasson, Y.; Shahak, I.; Tsaroom, S.; Blum, J. *J. Org. Chem.* **1978**, *43*, 4271. (e) Hassner, A.; Galle, J. E. *J. Am. Chem. Soc.* **1970**, *92*, 3733.

(3) Sundberg, R. J.; Pearce, B. C. *J. Org. Chem.* **1982**, *47*, 725.

0022-3263/87/1952-3956$01.50/0