Photochemistry of Host-Guest Complex. III.[1] Effect of Guest Cation on the Photoreactivity of Acetophenone Oxime Derivatives Having Crown Ether Moiety

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The *syn-anti* isomerization of acetylbenzocrown ether oximes was stimulated by the complex-formation with sodium ion. The photolysis of these oximes gave mother ketones and amides through an oxaziridine intermediate. The photolysis of the oximes was depressed by the formation of host–guest complexes. Reactivity in the photolysis of the crown ether oximes corresponds to that of 3,4-dimethoxyacetophenone oxime, whereas the reactivity of the complexed crown ether oxime with sodium ion corresponds to that of *p*-cyanoacetophenone oxime. Such behavior is explained by the change of the electronic properties of excited states of acetophenone oxime chromophore, which enhances the intersystem crossing.

Few photochemical reactions of crown ether and cryptand have been reported, though these classes of compounds are the targets of active current research.[2] Hautala and Hasting[3] observed the stimulated type II fission of monovalery-dibenzo-18-crown-6 by the formation of the complexes with alkali metal ions. In our earlier study,[4] the photochemical cross coupling between 18-crown-6 and alkyl aryl ketones was enhanced by the introduction of a cyano group or a potassium salt of carboxylato-group at the terminal position of the alkyl aryl ketone. These groups form complexes with crown ether and can hold radical pairs nearby by host–guest interaction or Coulomb interaction. Now we report the photochemical behavior of acetylbenzocrown ether oximes.

Experimental

Syntheses of Oximes. A mixture of benzo-15-crown-5 (930 mg, 3.5×10^{-3} mol), acetic acid (240 mg, 4.0×10^{-3} mol), and polyphosphoric acid (15 ml) was heated to 80 °C for 3 h under stirring. After cooling, the mixture was diluted with 30 ml of water under further cooling and stirred for 30 min to hydrolyse the polyphosphoric acid. The precipitate was combined with the chloroform extract and washed with saturated sodium hydrogencarbonate solution and water. Evaporation of chloroform after drying over magnesium sulfate gave a pale yellow solid. Recrystallization of the solid from ethanol gave acetylbenzo-15-crown-5 (**3b**) (40% yield). Mp, 93—95 °C: IR($CHCl_3$), 1665 cm^{-1}; NMR ($CDCl_3$) (δ), 2.50 (3H, s), 3.67—4.30 (crown ether), 6.78 (1H, d, J=9 Hz), and 7.51 (2H, m).

A mixture of acetylbenzo-15-crown-5 (**3b**) (200 mg, 6.5×10^{-4} mol), hydroxylamine hydrochloride (70 mg, 1.0×10^{-3} mol), and potassium acetate (100 mg, 1.5×10^{-3} mol) was heated under reflux for 2 h in a mixed solvent of ethanol, chloroform, and water (10: 3: 2). After cooling, the reaction mixture was diluted with 10 ml of water. Chloroform extraction (20 ml×3) of the mixture gave a pale yellow solid after conventional work-up. Recrystallization from methanol gave a colorless acetylbenzo-15-crown-5 oxime (**1b**) in 75% yield. Mp, 133—135 °C. Found: C, 58.75; H, 7.02; N, 4.38%. Calcd for $C_{16}H_{23}NO_6$: C, 59.06; H, 7.13; N, 4.31%. $\lambda_{max}^{CH_3CN}$ 263 (17300) and 294 nm (7050); IR ($CHCl_3$): 3560, 3450—3100, 1599, 1503, 1419, and 1130 cm^{-1}; NMR ($CDCl_3$) (δ): 2.21 (3H, s), 3.69—4.22 (crown ether), 6.78 (1H, d, J=9 Hz), 7.10 (1H, dd, J=9 and 1 Hz), 7.21 (1H, d, J=1 Hz), and 8.75 (1H, br, s).

The same procedure gave acetylbenzo-18-crown-6 oxime (**1c**). Mp, 106—107 °C. Found: C, 58.21; H, 7.67; N, 3.84%. Calcd for $C_{18}H_{27}NO_7$: C, 58.52; H,7.37; N, 3.79%. IR ($CHCl_3$): 3560, 3450—3100, 1602, 1510, 1432, and 1140 cm^{-1}; NMR ($CDCl_3$) (δ): 2.24 (3H, s) 3.68—4.34 (crown ether), 6.84 (1H, d, J=9 Hz), 7.12 (1H, dd, J=9 and 1 Hz), 7.23 (1H, d, J=1 Hz), and 9.20 (1H, br, s).

Acetophenone Oxime Derivatives. 3,4-Dimethoxyacetophenone oxime (**1a**), acetophenone oxime, *p*-chloroacetophenone oxime, *p*-methoxyacetophenone oxime, and *p*-cyanoacetophenone oxime were synthesized from the mother ketones in the manner used for the preparation of acetylbenzo-15-crown-5 oxime (**1b**); these oximes have the reported physical constants.

General Procedure of Photochemical Reaction. One of the oximes in 10 ml of appropriate solvent was placed in a Pyrex tube (unless otherwise mentioned) and irradiated externally by using a Rikosha rotary irradiation-apparatus equipped with a 450 W high pressure mercury lamp mounted in a quartz cooling jacket. The distance between tubes and the lamp was *ca.* 5 cm. The absorption spectra of the oximes (**1a**, **1b**, and **1c**) show large extinction coefficients around the emission lines of the lamp at 302.5 and 313 nm and no absorption is seen at 366 nm. The spectra were changed only slightly by addition of sodium, potassium, or tetramethylammonium salts. The concentration of the oximes for irradiation were arranged to absorb more than 99.9% of the emission-light from the lamp at 302.5 and 313 nm, so that all samples in the rotary irradiation-apparatus absorb essentially equal number of photons.

Geometrical Isomerization. A preparative scale experiment was carried out in acetonitrile by irradiation of one of the oximes (5.0×10^{-2} mol/dm^3, 10 ml) for 6 h. The reaction mixture was separated by chromatography on a silica gel plate eluted with chloroform–ethyl acetate (2: 1). The *syn*-isomer of 3,4-dimethoxyacetophenone oxime (**1a**) gave almost identical IR and NMR spectra to its *anti*-isomer, but the chemical shift of acetoxime methyl is slightly different. 3,4-Dimethoxyacetophenone oxime (**1a**): *anti*-isomer (δ,2.26); *syn*-isomer (δ, 2.19). Acetylbenzo-15-crown-5 oxime (1b) has a similar spectral property: *anti*-isomer (δ, 2.21); *syn*-isomer (δ, 2.19). Recrystallization of the *syn*-isomer formed photochemically gave original *anti*-isomer.

A solution (1.6×10^{-1} mol/dm^3) of one of the oximes (**1a** or **1b**) placed in an NMR sample tube was irradiated in the presence of sodium perchlorate, and the ratio of *syn*- and *anti*-oxime was determined by NMR analysis using the relative intensity of the acetoxime methyls.

Photolyses in Acetic Acid. One of the oximes (**1a** or **1b**)

in anhydrous acetic acid was irradiated until the starting material disappeared. Evaporation of the solvent *in vacuo* and chromatography on an alumina column eluted with chloroform gave the products. The products were further separated by chromatography on a silica gel plate. This was eluted with chloroform–ethyl acetate (2 : 1) for the products from dimethoxyacetophenone oxime (**1a**) and with chloroform–ethyl acetate–methanol (2: 1: 0.1) for the products from acetylbenzo-15-crown-5 oxime (**1b**). The mother ketones were obtained as major products (*ca.* 70%) and two types of amide (**4a, 4b**), with arene migration and methyl migration respectively, were obtained in *ca.* 30% yield.

An acetic acid solution (6.25×10^{-2} mol/dm^3, 10 ml) of one of the oximes (**1a** or **1b**) combined with various amounts of sodium acetate was irradiated for only 10 min. Within this period less than 0.1% of the starting oxime was converted to oxaziridine. Immediately after irradiation the solution were combined with an aqueous solution of potassium iodide and starch under magnetic stirring; then the mixture was allowed to stand for 10 min. These solutions were titrated with aqueous sodium thiosulfate. The results are shown in Table 1.

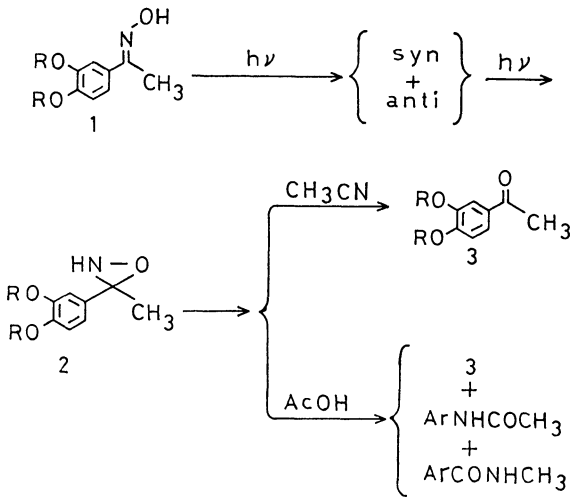
Photolysis in Acetonitrile. One of the oximes (**1a, 1b, 1c**) (5.0×10^{-2} mol/dm^3) in acetonitrile–water (20 : 1) was irradiated until the starting oxime disappeared. Evaporation of the solvent and chromatography gave the mother ketone in quantitative yield.

Various amounts of sodium, potassium, or tetramethylammonium salts were added to an acetonitrile solution (5.0×10^{-2} mol/dm^3, 10 ml) of one of the oximes. The mixture was irradiated until 30—40% of the starting oxime disappeared (10—15 h), then the reaction mixture was condensed *in vacuo*. The residue was extracted three times with chloroform (20 ml×3). After drying over magnesium sulfate the combined extract was condensed to about 3 ml and the precipitated sodium perchlorate was removed. The filtrate was further condensed and analyzed by NMR spectroscopy in deuteriochloroform containing measured amount of tetrachloroethane as an internal reference. This procedure can extract both complexed and non-complexed acetylbenzo-15-crown-5 (**1b**) almost completely and hence the relative yield of **3** can be determined with reasonable accuracy. The results thus obtained for **1b** and **1c** are shown in Figs. 2 and 3.

Photolysis of Acetophenone Oxime Derivatives. An acetonitrile solution (5.0×10^{-2} mol/dm^3, 10 ml) of one of the oxime derivatives was irradiated for 16 h; less than 20% of the starting oximes were consumed within this period. The work-up used for the photolysis of the oximes (**1a, 1b, 1c**) and NMR analyses using tetrachloroethane as an internal reference gave the results shown in Fig. 4.

Results and Discussion

Irradiation of 3,4-dimethoxyacetophenone oxime (**1a**) caused *syn-anti* isomerization at the early stage. Further irardiation gave the mother ketone (**3a**) in quantitative yield in acetonitrile containing or not containing water. Prolonged irradiation of (**1a**) in glacial acetic acid gave two amides, formed by photochemical Beckmann rearrangement, as minor products (*ca.* 30%) in addition to the mother ketone (**3a**) (*ca.* 70%). In the same manner, acetylbenzo-15-crown-5 oxime (**1b**) and acetylbenzo-18-crown-6 oxime (**1c**) gave similar products to those obtained in the case of oxime (**1a**). One type of amide was identical to the authentic sample prepared by Beckmann rearrangement of the *anti*-oximes by the



1a, 2a, 3a: R=CH_3
1b, 2b, 3b: R=-$(CH_2CH_2O)_3CH_2CH_2$-
1c, 2c, 3c: R=-$(CH_2CH_2O)_4CH_2CH_2$-

Scheme 1.

catalysis of sulfuric acid. This type of amide must be formed by migration of arene moiety. Though the structure of the other type of amide has not been studied in detail, its NMR spectra show clearly the existence of the *N*-methyl group (δ, 2.95), and hence the amide must be formed by methyl migration. The photoreactivity of oximes should be the same, whether or not they contain crown ether moiety.

Geometrical Isomerization. The effect of sodium perchlorate on *syn-anti* isomerization is changed by the introduction of crown ether moiety into the oxime. As shown in Fig. 1, the isomerization of acetylbenzo-15-crown-5 oxime (**1b**) in chloroform–methanol (3 : 4) was stimulated in the presence of sodium perchlorate. On the other hand, the isomerization of 3,4-dimethoxyacetophenone oxime (**1a**) was only slightly affected. These results clearly show that the complexation of

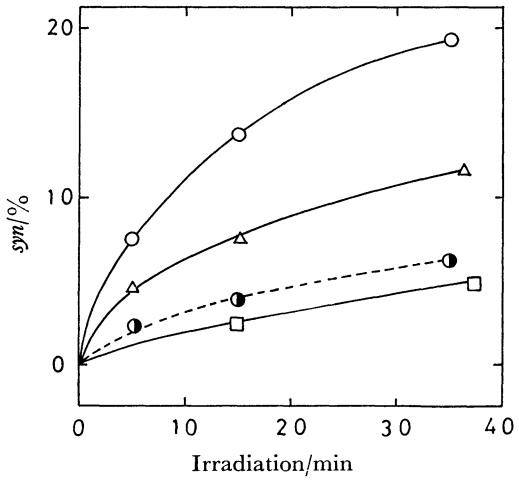


Fig. 1. Geometrical isomerization of **1a** and **1b** (1.6×10^{-1} mol dm^{-3}) in $CHCl_3$–CH_3OH (3: 4).
□—□: **1a** or **1b** without added salt, ◑···◑: **1a**+$NaClO_4$ (1.06 mol dm^{-3}), △—△: **1b**+$NaClO_4$ (0.16 mol dm^{-3}), ○—○: **1b**+$NaClO_4$ (1.06 mol dm^{-3}).

sodium cation stimulates the isomerization of crown ether oxime (**1b**). Geometrical isomerization of an oxime has been reported to take place from a triplet excited state.[5] The complexation of (**1b**) must therefore increase the quantum yield of this triplet state.

Oxaziridine Formation. A mother ketone and two amides are believed to form photochemically through an oxaziridine intermediate.[5,6] We analyzed the oxaziridine by iodometry[6] at the very early stage of photolysis (10 min) in glacial acetic acid. Only 0.1% of oxaziridine was formed within this period, so secondary photolysis to produce the mother ketone and amides shoud be negligible. Therefore, the values obtained by iodometry must be a good measure of relative quantum yield of the oxaziridine intermediate (**2**) in the presence of sodium acetate (see Table 1).

TABLE 1. RELATIVE QUANTUM YIELDS OF OXAZIRIDINE FORMATION FROM **1a** AND **1b** IN THE PRESENCE OF SODIUM ACETATE

Added NaOAc[a]	Starting oxime	
	1a[b]	**1b**[b]
0.0	1.00	1.00
5.0	0.76	0.82
10.0	0.60	0.68
15.0	0.53	0.48
20.0	0.51	0.29

a) Molecular equivalents of NaOAc to the oxime. b) 6.25×10^{-2} mol dm^{-3} solution of **1a** and **1b** in acetic acid was used.

The relative quantum yield of oxaziridine formation from acetylbenzo-15-crown-5 oxime (**1b**) deviates from those of 3,4-dimethoxyacetophenone oxime (**1a**) in somewhat higher concentrations of the added sodium acetate. The formation constant of the complex between **1b** and sodium acetate was determined by Benesi-Hildebrand method;[7] the value is very small (K=2—3 M^{-1}) in acetic acid. The small formation constant must be one of the major factors of the salt effect only in the higher concentration range.

The photochemical formation of oxaziridine from an oxime has been reported to occur from a singlet state.[5,6] Hence the complexation seems to retard the process involving a singlet excited state of crown ether oxime (**1b**). The similar decrease in the quantum yields for both **1a** and **1b** in the lower concentration range of the added salt must be due to the basic nature of sodium acetate. It has been established that a base inhibits the photolysis of an oxime.[8]

Formation of Mother Ketones. Prolonged irradiation of the oximes (**1a**, **1b**, and **1c**) in acetonitrile containing or not containing water gave only the mother ketones. Fig. 2 shows the effect of sodium salts on photolyses, The mother ketone must be derived from the oxaziridine intermediate by a photochemical or thermal process.[6] Since no other product than the mother ketone was obtained, the relative quantum yield of the ketone must be a reasonable reflection of the formation of oxaziridine intermediate, whatever the

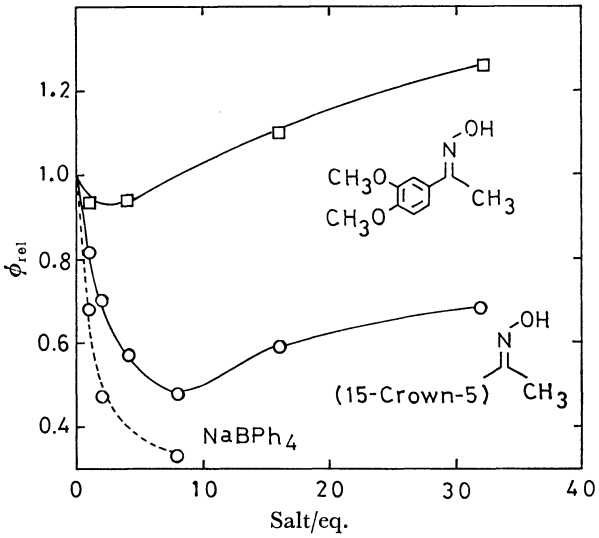


Fig. 2. Relative quantum yield of the mother ketone on photolysis of **1a** (1.3×10^{-1} mol dm^{-3}) and **1b** (5.0×10^{-2} mol dm^{-3}) in CH_3CN-H_2O (20: 1) in the presence of sodium salt.
□—□: **1a**+$NaClO_4$, ○—○: **1b**+$NaClO_4$, ○···○: **1b**+$NaBPh_4$.

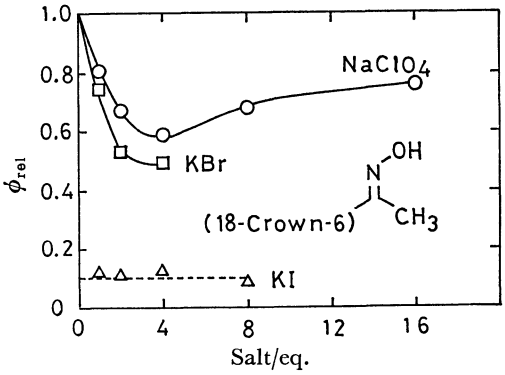


Fig. 3. Relative quantum yield of the mother ketone on photolysis of **1c** (5.0×10^{-2} mol dm^{-3}) in CH_3CN-H_2O (20: 1) in the presence of alkali metal salts.
○—○: $NaClO_4$, □—□: KBr, △···△: KI.

mechanism of formation is. The photolysis of acetyl-15-crown-5 oxime (**1b**) was depressed by sodium salts in the lower concentration range. By contrast, 3,4-dimethoxyacetophenone oxime (**1a**) showed only a slight effect. Recovery of the reactivity is seen in both types of oxime in higher concentration range of the added sodium perchlorate; this effect can be accounted for by the enhanced acidity or the polarity of the reaction media. It is well established that the photolysis of oxime is stimulated by acidic or polar conditions.[8-10] The effect of complex formation on the reactivity, therefore, must be limited to the lower concentration range of the added sodium perchlorate. The Benesi-Hildebrand method[7] gave the formation constant of *ca.* 5×10^2 M^{-1} for the complex between crown ether oxime (**1b**) and sodium ion from perchlorate in acetonitrile. Sodium tetraphenylborate depressed the photolysis strongly, though the effect in higher concentration could not be tested due to the insolubility of the

salt. A similar result was obtained with crown ether oxime (**1c**). Potassium salts were more effective. In the case of potassium iodide, however, a different mechanism must be operative to account for its powerful quenching. An electron transfer from iodide ion to the excited oxime is the most probable mechanism.[11]

Mechanism of Salt Effect. Hitherto discussed phenomena suggest that the effect of alkali metal salts on the photoreactivity of crown ether oximes differs to some extent according to the counter ion of the salts. So we can not deny the effect of perchlorate anion on the reactivity of crown ether oximes in the presence of sodium perchlorate, but the photolysis of 3,4-dimethoxyacetophenone oxime (**1a**) and acetylbenzo-15-crown-5 oxime (**1b**) were little affected by the addition of tetramethylammonium perchlorate. Therefore, it is clear that the difference in the effect of sodium perchlorate on **1a** and **1b** must be due to the formation of host–guest complexes between crown ether oxime and sodium cation. The slightly concave curve for oxime (**1a**) in Fig. 2 may indicate a weak chelation of sodium ion by the dimethoxybenzene moiety of **1a**.

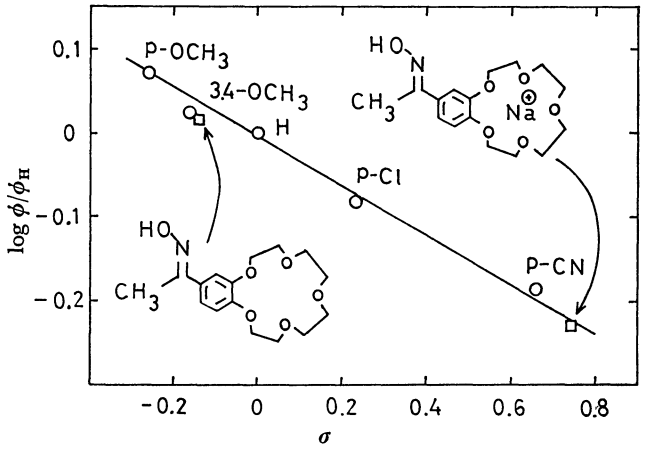
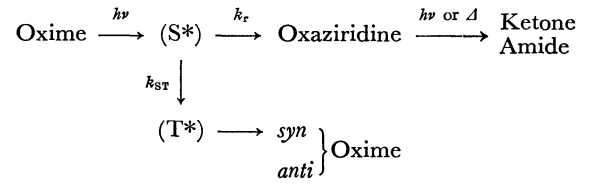


Fig. 4. Relative quantum yield of the mother ketones from acetophenone oxime derivatives (5.0×10^{-2} mol dm^{-3}) in CH_3CN.

Complexation of a cation in the cavity of crown ether must reduce the electron donating ability of alkoxyl groups. Such a change must affect the nature of both the excited state and the ground state of aromatic oximes. Actually the photoreactivity of acetophenone oxime derivatives varies depending on the electronic nature of the substituent on the benzene ring (see Fig. 4). The oxime having an electron donating substituent has higher reactivity than the oxime having an electron withdrawing substituent. Though we can not clarify the exact nature of the excited state responsible for the photolysis, the relative quantum yields of the ketone formation from acetophenone oxime derivatives in acetonitrile show a linear correlation with Hammet σ-constant. The photoreactivity of free crown ether oxime (**1b**) corresponds to that of oxime (**1a**), and the reactivity of the complexed **1b** with sodium ion, obtained by extrapolation of the curve in Fig. 2, corresponds to *p*-cyanoacetophenone oxime. The complexation of crown ether oxime (**1b**) with sodium ion induces a slight change in its electronic absorption spectrum, a small hypsochromic shift (*ca.* 3 nm) and a small decrease in extinction coefficient, but the complexation may affect the nature of the excited state more profoundly.

The photochemistry of oximes can be summarized by the scheme shown below, which was established by



Mukai and Oine[6] and de Mayo *et al.*[5] A singlet state of oxime gives an oxaziridine, which affords a mother ketone and an amide on further photolysis or thermal process. A triplet excited state, on the other hand, causes geometrical isomerization. Our findings show that the formation of a host–guest complex stimulates the geometrical isomerization and depresses the formation of oxaziridine. The present results and the general scheme indicate that the ratio of the rate of intersystem crossing to the rate of oxaziridine formation (k_{ST}/k_r) becomes larger with the host–guest complex than with the free crown ether oxime. There are a several possible explanations of this behavior. First, the spin-orbital coupling may vary by complex formation due to a heavy atom effect and modify the rate of intersystem crossing (k_{ST}); but a light atom such as sodium usually does not show such a heavy atom effect.[12] Second, the difference in energy gap between a singlet and a triplet excited state (ΔE_{ST}) may alter the rate of intersystem crossing (k_{ST}). Unfortunately, these oximes are non-emissive, at least in the solvent system used for photoreaction, and no direct information on the excited state was available. However, the change in electronic absorption spectra was not remarkable by complex formation—a small hypsochromic shift of *ca.* 3 nm—and we do not consider this factor to be important. Third, any electronic property of the excited state must affect both k_r and k_{ST}. In analogy with alkyl aryl ketones,[13] the excited state of the acetophenone oxime derivatives must reduce the $n\pi^*$ character of the singlet state by introduction of an electron donating substituent such as alkoxyl group and diminish the rate of intersystem crossing, $(n\pi^*)^1\rightarrow(\pi\pi^*)^3$. On the other hand, an electron withdrawing substituent such as cyano group enhances an $n\pi^*$ nature of the singlet state and hence the rate of intersystem crossing. This concept is reasonable, since the intersystem crossing $(n\pi^*)^1\rightarrow(\pi\pi^*)^3$ is larger than the intersystem crossing $(\pi\pi^*)^1\rightarrow(\pi\pi^*)^3$.[14] This is the most reasonable explanation for the depression of the formation of oxaziridine which affords the mother ketone and amides, and the stimulated geometrical isomerization from $(\pi\pi^*)^3$. We believe the variation in the electronic property of the excited states is the most important factor in characterizing the photochemical behavior of the host–guest complex of acetylbenzocrown ether oximes.

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