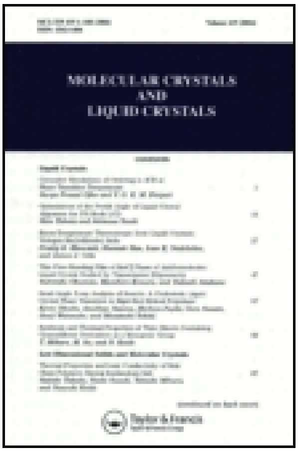

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EZ-Isomerization of α,β-punsaturated Acid Derivatives in the Solid State

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EZ-ISOMERIZATION OF α,β-UNSATURATED ACID DERIVATIVES IN THE SOLID STATE

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Abstract The solid-state *EZ*-isomerizability of α,β-unsaturated amide was greatly improved by modifying their structure, which had low isomerizability in the solid state; *EZ*-isomerizability was attained by replacing the carbonyl group of the amides by a thiocarbonyl group as well as replacing the heterochiral *N*-substituent of the amides by a homochiral one. Furthermore, *EZ*-photoisomerization was also attained for several kinds of salts of α,β-unsaturated carboxylic acids with amines. This photoreaction was proven to be an effective method for preparing (*Z*)-isomers from ammonium (*E*)-α,β-unsaturated carboxylates. The isomerizability was strikingly altered upon changing the ammonium part, which implied that the crystal structure affected the reactivity to a considerable extent. A further detailed study concerning the crystal structures suggested that the characteristic of the hydrogen-bond network had a close correlation with the isomerizability. Moreover, both the bulkiness of the carboxylate and ammonium parts as well as their difference in length were considered to be the most important factors influencing the isomerizability.

INTRODUCTION

In recent decades, the crystalline environment has been attracting much attention, since it can control the selectivity of reactions.[1] Although a number of photoreactions have been performed in the solid state,[2] *EZ*-isomerization is still not well studied compared to other photoreactions,[1,3] since a drastic movement of a molecule in the crystal is required along with the reaction, which is unfavorable for a reaction in the solid state.

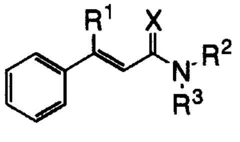
During a continuous study of the solid-state photoreaction of α,β-unsaturated carboxylic acid derivatives, we recently found that *EZ*-isomerization occurred in the solid state in the cases of amides and thioamides with a complete or partial depression of another photoreaction, such as a deconjugation reaction.[4] In addition, we also found that ammonium salts of α,β-unsaturated carboxylic acid underwent *EZ*-isomerization selectively in the solid state to give its (*Z*)-isomer in high yield.[5] This result indicates two attractive aspects: The reactivity in the solid state would be controlled by a change of the ammonium moiety, and the behavior of the reaction could be systematically studied using miscellaneous ammonium salts. Moreover, it is also expected that solid-state *EZ*-isomerization would be realized for general α,β-unsaturated carboxylic acids.

In the present article, we review the *EZ*-isomerization reaction of α,β-unsaturated carboxylic acid derivatives in the solid state carried out in our laboratory.

PHOTOREACTION OF α,β-UNSATURATED AMIDES AND THIOAMIDES IN THE SOLID STATE[4]

As the substrates for the photoreaction in the solid state, α,β-unsaturated amides **1a–e** (see Fig. 1), were prepared by ordinary procedures. Among them, **1c** could not be a substrate, since it was a liquid at room temperature. Upon irradiation of **1a–e** (except for **1c**) in the solid state, only amide **1d** showed photoreactivity; **1d** gave (*Z*)-isomer **2d** and deconjugated product **3d** in moderate yields (Table I, Entry 7), while the other amides were photo-stable (Entries 1, 3, and 9). Although the solid-state photoisomerizability of these α,β-unsaturated amides was generally quite low, the result of the photoreaction of **1d** arose the expectation that the solid-state *EZ*-isomerization of α,β-unsaturated compounds might occur under appropriate conditions, which would be achieved by modifying the structure of **1a–e**.

As the first modification of these amides, we considered to convert the carbonyl



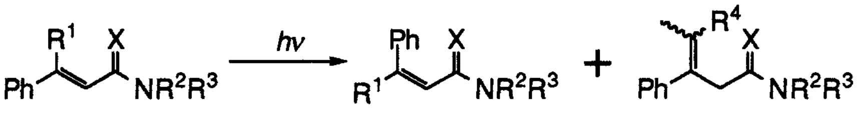
	R^1	R^2	R^3	X
1a	Et	Ph	Ph	O
1b	Et	Ph	Me	O
1c	Et	$-(CH_2)_5-$		O
1d	Et	–CHMePh-(*RS*)	H	O
1e	Pr^i	–CHMePh-(*RS*)	H	O
1f	Et	Ph	Ph	S
1g	Et	Ph	Me	S
1h	Et	$-(CH_2)_5-$		S
1i	Et	–CHMePh-(*R*)	H	O
1j	Pr^i	–CHMePh-(*R*)	H	O

FIGURE 1 Chemical structures of amides and thioamides.

group of amides **1a–c** to a thiocarbonyl group, since this chromophore generally requires a lower excitation energy and has a lower hydrogen-abstracting ability than does a carbonyl group.[6] Also, thioamides crystallize more easily than do amides.

The results for the irradiation of thioamides **1f–h** in the solid state are summarized in Table I (Entries 2, 4, and 6). It is worth noting that thioamide **1h** solidified at room temperature, in contrast to the fact that the corresponding amide **1c** was a liquid. As can be seen from Table 1, the photoisomerizability was tremendously

TABLE I Photoreaction of α,β-unsaturated amides and thioamides in the solid state.



1 **2** **3**: R^4 = H or Me

Entry	Compound	Irradiation time	Photoreactivity	Products ratio[a] **1**: **2** : **3**
1	**1a**	5 min[b]	stable	100 : 0 : 0
2	**1f**	24 h	reactive	18 : 82 : 0
3	**1b**	5 min[b]	stable	100 : 0 : 0
4	**1g**	95 h	reactive	77 : 23 : 0
5	**1c**[c]	—	—	—
6	**1h**	24 h	reactive	48 : 52 : 0
7	**1d**	24 h	reactive	36 : 42 : 22
8	**1i**	24 h	reactive	24 : 70 : 6
9	**1e**	5 min[b]	stable	100 : 0 : 0
10	**1j**	72 h	reactive	60 : 40 : 0

a) Determined by a ^{1}H NMR analysis of the irradiated sample.

b) Irradiation was performed on a sample dispersed in a KBr pellet.

c) Not crystallized.

improved by converting the carbonyl group of the amides to a thiocarbonyl group; each of **1f–h** showed a high-moderate photoreactivity in the solid state to give the corresponding (*Z*)-isomer as the sole product. In the case of **1f**, the selectivity for *EZ*-isomerization was realized in the solid-state photoreaction; the irradiation of **1f** in chloroform gave a very complicated mixture, while that in the solid state resulted in the exclusive formation of the (*Z*)-isomer.

As the second modification of the amides, we replaced the heterochiral 1-phenylethyl moiety of **1d** and **1e** with a homochiral one on the basis of the fact that a homochiral compound usually affords a different crystal lattice from that of the corresponding heterochiral counterpart.[7] Thus, homochiral amides **1i** and **1j** (see Fig. 1) were prepared. As a result, the solid-state photoisomerizability of **1d** was considerably improved by replacing the heterochiral 1-phenylethyl moiety with a homochiral one; when homochiral **1i** was irradiated in the solid state, the yield of the deconjugated product decreased, whereas that of the (*Z*)-isomer increased (compare Entries 7 and 8 in Table I). Moreover, in the case of **1e**, a considerable change in the photoreactivity was observed upon replacing the heterochiral 1-phenylethyl moiety with a homochiral one. Namely, homochiral **1j** showed moderate photoreactivity in the solid state to afford (*Z*)-isomer **2j** as the sole photoproduct (Table I, Entry 10). This result is in contrast to the fact that **1e** was photo-stable in the solid state (Table I, Entry 9).

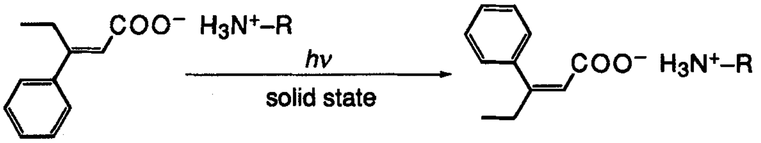
Thus, it was found that the solid-state *EZ*-isomerization of α,β-unsaturated carboxylic acid derivatives could be achieved by employing α,β-unsaturated thioamides. Moreover, the photoisomerizability as well as the selectivity of the reaction of α,β-unsaturated amide was tremendously improved upon introducing homochirality into the amide skeletons.

PHOTOREACTION OF AMMONIUM α,β-UNSATURATED CARBOXYLATES IN THE SOLID STATE[5]

We then tried to control the *EZ*-photoisomerizability of α,β-unsaturated carbonyl compounds in the solid-state by a non-covalently-bonded moiety. We carried out the solid-state photoirradiation of ammonium salts of α,β-unsaturated carboxylic acids, based on the consideration that the photoisomerizability of the α,β-unsaturated carboxylate anions could be controlled by changing the ammonium moiety.

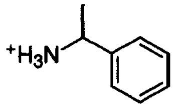
At first, (±)-1-phenylethylammonium (*E*)-3-phenyl-2-pentenoate (***E*-2a**) was chosen as a substrate, which afforded both *Z*-isomer **Z-2a** and the deconjugated photoproduct upon irradiation in a solution. Irradiation of ***E*-2a** in the solid state resulted in the selective formation of (*Z*)-isomer ***Z*-2a**; crystalline ***Z*-2a** was obtained in 80% yield, while neither the [2+2] cycloadduct nor the Norrish type-II hydrogen-abstracted product was obtained at all. Then, the solid-state photoirradiation of ***E*-2b-d**, which had different ammonium moieties from that of ***E*-2a**, was performed. The results are summarized in Table II. The reactivity of ***E*-2** in the solid state considerably altered upon changing the ammonium part. In contrast, the crystalline salts of ***Z*-2** were found to have extremely low reactivity. These results suggested that the *EZ*-isomerization of ***E*-2** in the solid state proceeds almost irreversibly to form the (*Z*)-isomer.

TABLE II *EZ*-Isomerization of ammonium salts of ***E*-2** in the solid state.

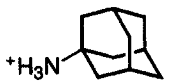


***E*-2a-d** ***Z*-2a-d**

salt	ammonium	*E* / *Z* ratio[a)]
***E*-2a**	**a**	20 / 80
***E*-2b**	**b**	40 / 60
***E*-2c**	**c**	86 / 14
***E*-2d**	**d**	92 / 8
***Z*-2a**	**a**	0 / 100
***Z*-2b**	**b**	0 / 100
***Z*-2c**	**c**	0 / 100
***Z*-2d**	**d**	7 / 93



a



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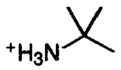

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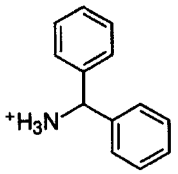
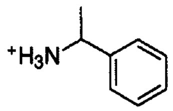


d

a) The ratio was determined by a ^{1}H NMR analysis after irradiation for 24 h with a 500-W super-high-pressure mercury lamp under an argon atmosphere.

TABLE III *EZ*-Isomerization of ammonium salts of (*E*)-α,β-unsaturated carboxylic acids in the solid state.

salt	R^1a)	R^2a)	R^3a)	ammonium	*E* / *Z* ratiob)
***E*-3a**	Ph	H	H	**a**	100 / 0
***E*-3f**				**f**c)	100 / 0
***E*-4a**	Ph	Me	H	**a**	6 / 94
***E*-4d**				**d**	33 / 67
***E*-5a**	Ph	H	Me	**a**	62 / 38
***E*-5f**				**f**c)	100 / 0
***E*-6a**	Me	H	H	**a**	77 / 23
***E*-6f**				**f**c)	81 / 19
***E*-7a**	Me	H	Me	**a**	85 / 15
***E*-7e**				**e**	100 / 0
***E*-8e**	Bu^t	H	H	**e**	74 / 26
***E*-8f**				**f**c)	63 / 37
***E*-9e**	Bu^t	Me	H	**e**	39 / 61
***E*-9f**				**f**c)	37 / 63d)



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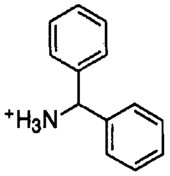

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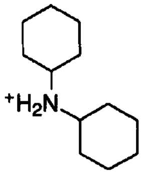
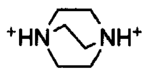
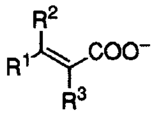


e



f

a)



b) The ratio was determined by a ^1H NMR analysis after irradiation for 24 h with a 500-W super-high-pressure mercury lamp at room temperature under an argon atmosphere.

c) Two equivalents of the carboxylic acid were used for the preparation of the salt.

d) Deconjugated product was obtained in 44% yield.

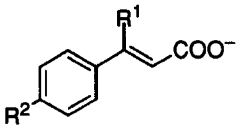
Then, the solid-state photoreaction was applied to various kinds of ammonium salts of (*E*)-α,β-unsaturated carboxylic acids (Table III). As a result, the (Z)-isomers could be obtained from a number of ammonium salts of (*E*)-α,β-unsaturated carboxylic acids upon irradiation in the solid state. In most cases, *EZ*-isomerization occurred exclusively; other photoreactions, such as the Norrish type-II reaction and the [2+2] photocycloaddition, did scarcely occur. Only ***E*-9f**, exceptionally, afforded a deconjugated product. In each case, the solid-state isomerizability of ammonium (*E*)-α,β-unsaturated carboxylates was dependent on the ammonium part, as was that of the ***E*-2** derivatives. A typical example was the photoreaction of ***E*-5**; the salt with (±)-1-phenylethylamine (***E*-5a**) afforded the (Z)-isomer in 38% yield, whereas the salt with 1,4-diazabicyclo[2.2.2]octane (***E*-5f**) afforded no (Z)-isomer upon photoirradiation in the solid state. The best result was achieved by the photoirradiation of (±)-1-phenylethylammonium 3-phenyl-2-butenoate (***E*-4a**) to afford the (Z)-isomer in 94% yield.

In order to investigate the relationship between the solid-state isomerizability and

TABLE IV Effect of substituent(s) on isomerizability in the solid state.

salt	$R^{1\,a)}$	$R^{2\,b)}$	*E* /*Z* ratio$^{c)}$
***E*-4a**	Me	H	6 / 94
***E*-2a**	Et		20 / 80
***E*-10a**	Pr^i		70 / 30
***E*-11a**	Hex^c		97 / 3
***E*-12a**	Et	Me	67 / 33
***E*-13a**		Cl	83 / 17
***E*-14a**		Bu^t	88 / 12

a), b) R^1, R^2 represent



c) Photoirradiation was performed for 24 h with a 500-W super-high-pressure mercury lamp at room temperature under an argon atmosphere. The product ratio was determined by a ^{1}H NMR analysis.

a chemical structure, we then carried out the solid-state photoirradiation of (±)-1-phenylethylammonium salts of (*E*)-α,β-unsaturated carboxylic acids, which have an arenyl group with a substituent different in bulkiness at the *p*-position and/or a substituent at the β-position (Table IV). It is worth noting that the yield of the (*Z*)-isomer strictly depends on the bulkiness of the substituents; the salt of (*E*)-α,β-unsaturated carboxylic acids having a smaller substituent(s) resulted in an increased formation of the (*Z*)-isomer.

Role of the Hydrogen-bond Network on the Isomerizability

The X-ray crystallographic analyses of these ammonium (*E*)-α,β-unsaturated carboxylates and their (*Z*)-isomers revealed that quite characteristic columnar hydrogen-bond networks were commonly formed in these salt crystals (Fig. 2), which were similar to those found in our previous study on conglomerate salts.[8] As a result of the detailed study on these hydrogen-bond columns, two structural characteristics were supposed to have an influence on the solid-state isomerizability. The first characteristic is the similarity in the topological structures of the hydrogen-bond columns between the (*E*)- and (*Z*)-isomers; for example, the topological structures of the hydrogen-bond columns of highly photoreactive ***E*-2a** and its photoproduct **Z-2a** are quite similar to each other (Fig. 3: The inter-columnar distances (d_1 and d_2), the angle between them (θ), and the length of *a*, *b*, or *c* (d_3), which is parallel to the axis of the hydrogen-bond column, are listed in Table V). This fact indicates that the change in alignment of the hydrogen-bond columns during the isomerization of ***E*-2a** into **Z-2a** is not so large. Namely, the isomerization proceeds with a small change in the whole crystal structure; such a small change is generally favorable for the solid-state reaction. In contrast, in a transformation

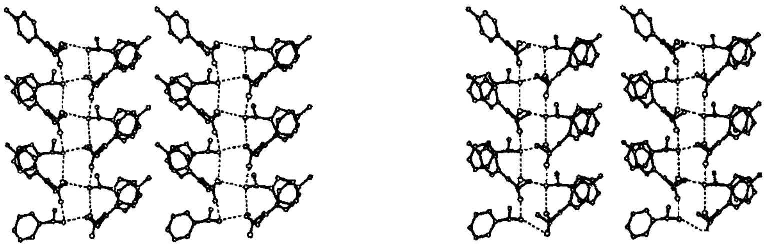


FIGURE 2 Stereodrawing of the hydrogen-bond column of ***E*-13a**

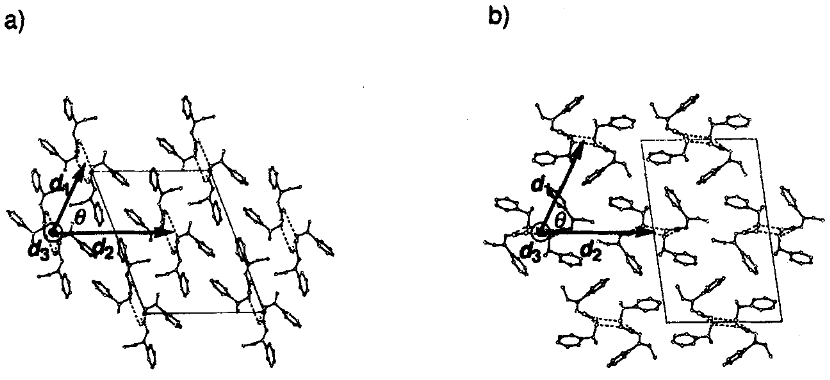


FIGURE 3 Crystal structures of a) ***E*-2a** and b) ***Z*-2a** viewed down the axis of the hydrogen-bond column. The dotted lines show the hydrogen bonds. The arrows represent the vectors to the two nearest-neighboring columns; d_1 and d_2 are the distances to them, respectively, and θ is the angle between them. d_3 is the length of the unit cells, which is parallel to the axis of the hydrogen-bond column.

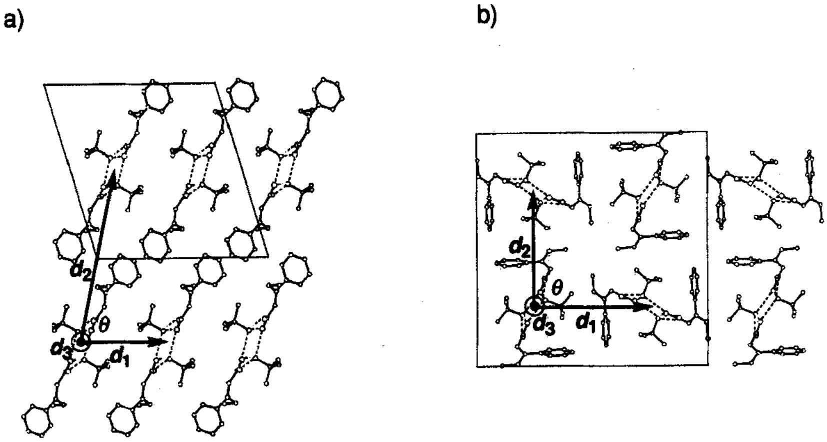


FIGURE 4 Crystal structures of a) ***E*-2c** and b) ***Z*-2c** viewed down the axis of the hydrogen-bond column. The dotted lines show the hydrogen bonds. The arrows represent the vectors to the two nearest-neighboring columns; d_1 and d_2 are the distances to them, respectively, and θ is the angle between them. d_3 is the length of the unit cells, which is parallel to the axis of the hydrogen-bond column.

TABLE V Distances and angle between hydrogen-bond columns.

salt	d_1 / Å	d_2 / Å	d_3[a] / Å	θ / °
***E*-2a**	9.84	14.94	6.44	64.92
***Z*-2a**	11.62	13.13	6.48	63.16
***E*-2c**	7.50	15.47	6.74	79.01
***Z*-2c**	10.80	10.80	6.47	90.00

a) The length of the unit cell *a*, *b*, or *c*, which is parallel to the axis of the hydrogen-bond column.

from ***E*-2c** to ***Z*-2c**, the change in the alignment of the hydrogen-bond columns during the isomerization is supposed to be tremendous, as can be seen from Fig. 4, which would arise from a large difference in length between the carboxylate and ammonium parts, unlike ***E*-2a**. Such a large change in the packing alignment of the hydrogen-bond columns in the crystal along with the reaction is considered to be quite unfavorable. Similarly, the relatively low isomerizability of ***E*-12a-14a** would be explainable, since the difference in length between the carboxylate and ammonium parts is enlarged by introducing a substituent at the *p*-position of the aromatic ring of the carboxylates.

The second characteristic is a difference in the packing around the carboxylate part in the hydrogen-bond column. In the case of highly photoreactive ***E*-2a**, the carboxylate part is loosely pushed to the hydrogen-bond column, indicating that the hydrogen-bond column is hardly deformed during isomerization. In contrast, the ammonium part of ***E*-2d**, which had low isomerizability regardless of the small difference in the length between the carboxylate and ammonium parts, makes the carboxylate part closer to the hydrogen-bond column upon replacing the methyl group of the ammonium part of ***E*-2a** by a large phenyl group (Fig. 5). This implies that a considerable deformation of the hydrogen-bond column occurs along with isomerization, which is energetically unfavorable. Furthermore, in the cases of ***E*-10a** and ***E*-11a**, which also had low isomerizability, the bulky substituent on the *β*-carbon of the carboxylate part is close to the other molecules in the identical hydrogen-bond column. Form these results, it was indicated that the bulkiness of both the carboxylate and ammonium parts has an influence on the isomerizability.

Thus, it seems that the isomerizability of the ammonium salt of an (*E*)-*α*,*β*-unsaturated carboxylate is controlled by the following two factors: a) The difference in length between the carboxylate and ammonium parts, which influences the change of the topological structure of the hydrogen-bond column during the isomerization, and b) the less-bulkiness of the carboxylate and ammonium parts, which would give an influence on the packing around the carboxylate part in the hydrogen-bond column.

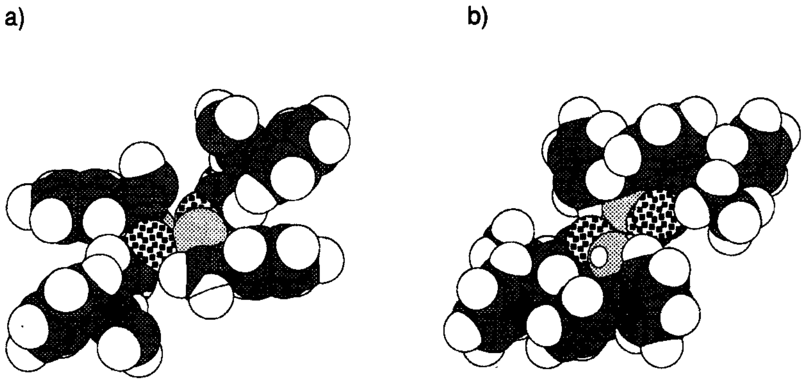


FIGURE 5 Space-filling model of the hydrogen-bond column of a) ***E*-2a** and b) ***E*-2d** viewed down the axis of the column.

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REFERENCES

1. V. Ramamurthy, Photochemistry in Organized and Constrained Media (VCH, New York, 1991).
2. V. Ramamurthy, R. G. Weiss, and G. S. Hammond, Advances in Photochemistry (ed by D. H. Voman, G. S. Hammond, and D. C. Neckers, John Willey and Sons, Inc., New York, 1993), Vol 18.
3. J. R. Scheffer, M. Garcia-Garibay, and O. Nalamasu, Organic Photochemistry (ed by A. Padwa, Marcel Dekker, New York, 1987), Vol 8, p. 318.
4. K. Kinbara and K. Saigo, Bull. Chem. Soc. Jpn., submitted.
5. K. Kinbara, A. Kai, Y. Maekawa, Y. Hashimoto, S. Naruse, M. Hasegawa, and K. Saigo, J. Chem. Soc., Perkin Trans. 2, in press.
6. M. Sakamoto, S. Watanabe, T. Fujita, and T. Nishio, Yuki Gosei Kagaku Kyokai Shi, 52, 658 (1994); M. Sakamoto, T. Ishida, T. Fujita, and S. Watanabe, J. Org. Chem., 57, 2419 (1992).
7. L. Jacques, A. Collet, S. H. Wilen, Enantiomers, Racemates, and Resolutions (Krieger Publishing Company, Malabar, Florida 1994).
8. K. Saigo, H. Kimoto, H. Nohira, K. Yanagi and M. Hasegawa, Bull. Chem. Soc. Jpn., 60, 3655 (1987).