

Highly Diastereoselective Photochromic Cyclization of an Indolyfulgide Derivative Possessing C_2 -Symmetric Chiral Diol as an Auxiliary

Yasushi Yokoyama,* Tomoyuki Okuyama, Yayoi Yokoyama,[†] and Masatoshi Asami

Department of Advanced Materials Chemistry, Graduate School of Engineering, Yokohama National University, 79-5 Tokiwadai, Hodogaya-ku, Yokohama 240-8501

[†]Department of Home Economics, Faculty of Home Economics, Tokyo Kasei Gakuin University, 2600 Aihara-cho, Machida, Tokyo 194-0292

(Received July 24, 2001; CL-010696)

An indolyfulgide derivative possessing an orthoester-type functional group on the acid anhydride moiety with a C_2 -symmetric (*S,S*)-1,2-bis(1-hydroxypropyl)benzene was prepared. Irradiation of 313-nm light produced the colored form in 90% diastereomer excess. The $[\alpha]_D$ values for the colorless and the colored forms in toluene were $+82^\circ$ and -420° , respectively.

The diastereoselective carbon–carbon bond formation in the ground state reactions has been one of the most important and therefore one of the most extensively studied organic chemistry of the last century.¹ However, the corresponding reactions in the excited states are left as the next challenging problem.² In particular, in the field of photochromism (i.e., the reversible photochemical reaction accompanied by a large change of absorption spectra), the importance of diastereoselective mutual interconversion has been announced because the change of chiroptical properties such as the optical rotation can be a probe to detect the state of the photochromic system by using the polarized light which is not absorbed by the photochromic isomers.^{3,4}

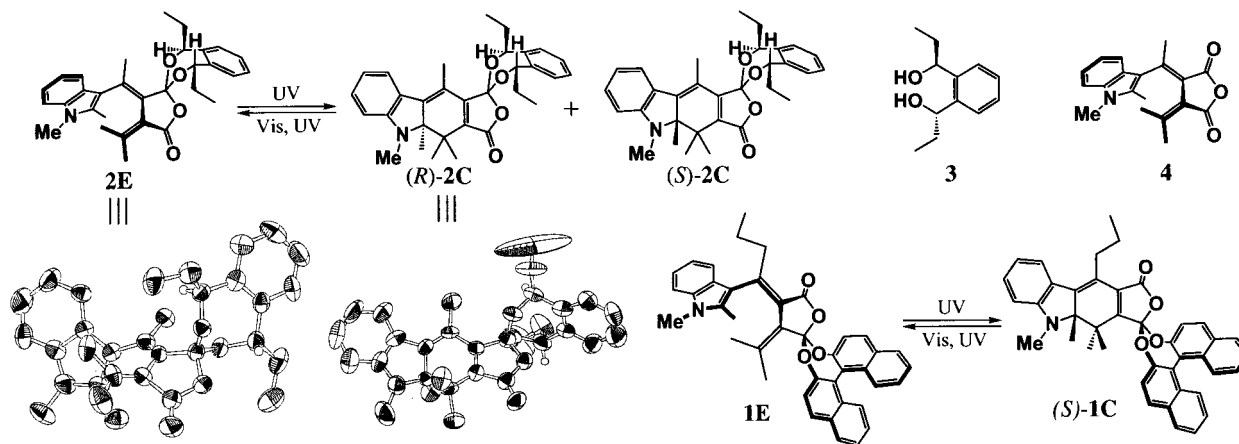
We have already reported that (*R*)-1,1'-bi-2-naphthol in **1E**, condensed with one of the carbonyl groups of an indolyfulgide, worked as the conformation-determining wedge so that the photogenerated **1C** showed 90% diastereomeric excess (de).^{4a} We here report another highly diastereoselective photochromic compound **2**, using (*S,S*)-1,2-bis(1-hydroxypropyl)benzene **3** as the chiral auxiliary. The enantioselective synthesis of **3** and the related compounds from 2-bromobenzaldehyde is reported separately.⁵

Synthetic route of **2** is shown in Scheme 1. Reaction of sodium alcoholate of **3** with an indolyfulgide **4**⁶ in THF pro-

duced the half ester. Treatment of the half ester with 2-chloro-1-methylpyridinium iodide and triethylamine in acetonitrile⁷ gave **2E** with small amount of inseparable by-products in about 6% yield from **4**. To isolate the photochromic **2E** and **2C**, the product thus obtained was irradiated with 366-nm light in ethyl acetate. The *C*-form, **2C**⁸ thus produced, was isolated as a pure diastereomer by silica-gel column chromatography and recrystallization. Irradiation of visible light to the solution of **2C** in ethyl acetate produced pure **2E**.⁹

X-ray crystallographic analyses of single crystals of **2E**⁹ and **2C**⁸ obtained above were done on a Rigaku AFC7R diffractometer with graphite monochromated Mo $K\alpha$ radiation and a rotating anode generator. The crystal structures in Scheme 1 gave us some interesting results: (1) Different from the synthesis of **1E**, the diol reacted on the carbonyl close to the indolyethylidene moiety during the synthesis of **2E**. (2) In the crystals, **2E** takes the *M* (left-handed) helicity with regard to the hexatriene moiety. As for the major diastereomer of **2C**, the absolute configuration of newly formed stereogenic carbon atom has (*R*)-configuration. Because the *M*-helicity of **2E** should generate (*R*)-**2C**, this result is quite plausible. However, PM3 molecular orbital calculations¹⁰ of (*M*)- and (*P*)-**2E** for possible conformational isomers showed little difference of heat-of-formation values. The experimental results may have come from the difference of reactivity of the excited states of both conformers.

This assumption was also supported by ¹H NMR measurements. In the ¹H NMR spectrum of **2E** in CDCl₃ at r.t., minor peaks are accompanying with some of the peaks of the major conformer,⁹ though **2E** behaved as a single compound on HPLC, TLC, and silica-gel column chromatography. Because the ratio of the peaks were about 4:1, the observed minor peaks cannot be



Scheme 1. Photochromism and ORTEP drawing of **2**.

Table 1. Absorption spectral data and quantum yields of **2** in toluene

$\lambda_{\max} / \text{nm}$ ($\epsilon_{\max} / \text{mol}^{-1} \text{dm}^3 \text{cm}^{-1}$)		313-nm light		489-nm light	2E : 2C
2C	2E	Φ_{FC}	Φ_{CF}	Φ_{CF}	at UV-pss
490 (7780)	328 (3050)	0.70	0.68	0.17	51 : 49

attributed to the conformer that gives the minor diastereomer of **2C** by photoirradiation, for the diastereomer ratio of **2C** was as large as 95:5 (vide infra). In addition, these peaks showed little change and were kept separated within the temperature range of $-50\text{ }^{\circ}\text{C}$ and $+60\text{ }^{\circ}\text{C}$.

Photoreaction of **2** was started from the recrystallized **2C** that contains only one diastereomer within the detection limit of HPLC. Irradiation of 489-nm light to the toluene solution of **2C** afforded **2E**. Irradiation of 313-nm light in turn gave the photostationary state (pss) composed of **2E** and **2C** (51/49).

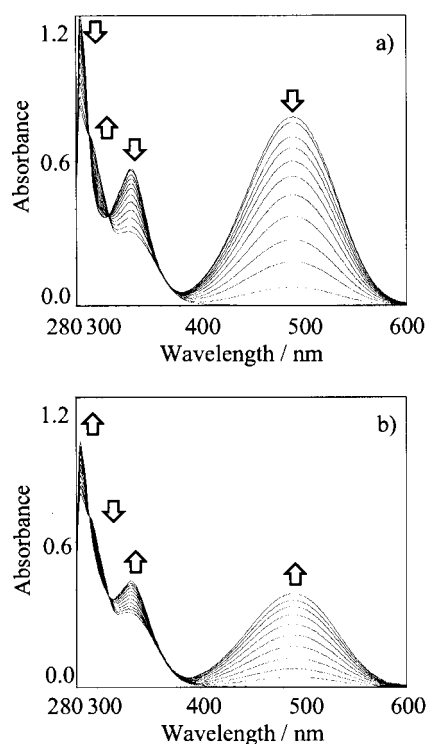


Figure 1. Absorption spectral change of **2** in toluene ($1.00 \times 10^{-4} \text{ mol dm}^{-3}$) upon irradiation with a) 489-nm light (**2C** to **2E**) and b) 313-nm light (**2E** to photostationary state).

The diastereoselectivity of cyclization of **2E** was monitored by HPLC using silica gel column. The ratio of two diastereomers of **2C** was determined to be 95/5 (90% de) for which the major isomer was the one used for X-ray crystallographic analysis.

Interestingly, no *Z*-form was observed either by ^1H NMR or by HPLC during UV irradiation. Because the upper region of **2** is sterically crowded, no **2Z** was formed.

The quantum yields of photoreactions and the spectroscopic properties of **2E** and **2C** in toluene were shown in Table 1.

The $[\alpha]_{\text{D}}$ value (in toluene (c 0.0049) at $28\text{ }^{\circ}\text{C}$) of **2E** was $+82^{\circ}$, while that of **2C** was -420° . At the pss, it was -176° . It should be noted that the sign of $[\alpha]_{\text{D}}$ values are different between **2E** and the pss. This may be of great merit when using $[\alpha]_{\text{D}}$ as the probe to detect the state of the photochromic system.

A PMMA film containing **2C** was stable at $80\text{ }^{\circ}\text{C}$ for more

than 10 days. Also, after the 10 times of the photochromic cycles of **2** in a PMMA film, more than 90% of **2** was remaining.

In conclusion, we have synthesized a new photochromic compound **2** possessing a C_2 -symmetric diol as the chiral auxiliary condensed with a carbonyl group of an indolylfulgide. The X-ray crystallographic analyses of **2E** and **2C** were done. The ring closure occurred with 90% de, and the sign of $[\alpha]_{\text{D}}$ values was altered by photoreactions.

The authors are grateful to Drs. Yoshitaka Yamaguchi and Hiroko Suezawa, Yokohama National University, for X-ray crystallographic analyses and variable-temperature ^1H NMR measurements, respectively, and Shorai Foundation for Science and Technology for financial support. This work has been done with the financial support of Grant-in-Aid for Scientific Research on Priority Area (A) "Molecular Synchronization for Design of New Materials System" (No. 11167235) from The Ministry of Education, Science, Sports and Culture of Japan.

References and Notes

- G. -Q. Lin, Y. -M. Li, and A. S. C. Chan, "Principles and Applications of Asymmetric Synthesis," Wiley Interscience, New York (2001).
- a) H. Rau, *Chem. Rev.*, **83**, 535 (1983). b) Y. Inoue, *Chem. Rev.*, **92**, 741 (1992).
- a) Y. Yokoyama, *Chem. Rev.*, **100**, 1717 (2000). b) B. L. Feringa, R. A. van Delden, N. Koumura, and E. M. Geertsema, *Chem. Rev.*, **100**, 1789 (2000).
- a) Y. Yokoyama, S. Uchida, Y. Yokoyama, Y. Sugawara, and Y. Kurita, *J. Am. Chem. Soc.*, **118**, 3100 (1996). b) Y. Yokoyama, Y. Shimizu, S. Uchida, and Y. Yokoyama, *J. Chem. Soc., Chem. Commun.*, **1995**, 785.
- M. Asami, M. Wada, and S. Furuya, *Chem. Lett.*, **2001**, 1110.
- a) A. Kaneko, A. Tomoda, M. Ishizuka, H. Suzuki, and R. Matsushima, *Bull. Chem. Soc., Jpn.*, **61**, 3569 (1988). b) S. Uchida, S. Yamada, Y. Yokoyama, and Y. Kurita, *Bull. Chem. Soc. Jpn.*, **68**, 1677 (1995).
- T. Mukaiyama, M. Usui, and K. Saigo, *Chem. Lett.*, **1976**, 49.
- 2C**: ^1H NMR (CDCl_3 , δ/ppm) 1.04 (3H, t, $J/\text{Hz} = 7.43$), 1.12 (3H, s), 1.13 (3H, t, $J/\text{Hz} = 7.26$), 1.26 (3H, s), 1.68 (3H, s), 1.88–2.22 (4H, m), 2.26 (3H, s), 2.88 (3H, s), 5.26 (1H, dd, $J/\text{Hz} = 7.59, 4.62$), 5.42 (1H, t, $J/\text{Hz} = 6.93$), 6.54 (1H, d, $J/\text{Hz} = 8.25$), 6.71 (1H, t, $J/\text{Hz} = 7.26$), 7.11 (1H, d, $J/\text{Hz} = 1.98$), 7.18–7.33 (4H, m), 7.56 (1H, d, $J/\text{Hz} = 7.92$); IR (KBr, ν/cm^{-1}) 1751, 1550, 1299; MS (EI, 70 eV, relative intensity) m/z 485 (M^+ , 60), 310 (43), 282 (71), 222 (100). Found: m/z 485.2560. Calcd for $\text{C}_{31}\text{H}_{35}\text{NO}_4$: $M = 485.2566$; Crystal data: $\text{C}_{31}\text{H}_{35}\text{NO}_4$, $M = 485.62$, orthorhombic, $P2_12_1$ (#18), $a = 21.592(4)\text{ \AA}$, $b = 10.291(2)\text{ \AA}$, $c = 12.404(3)\text{ \AA}$, $V = 2756.2(9)\text{ \AA}^3$, $Z = 4$, $\mu = 0.77\text{ cm}^{-1}$, $R = 0.063$, $R_w = 0.048$.
- 2E**: ^1H NMR (CDCl_3 , δ/ppm) 0.92 (3H, s), 0.95 (3H, t, $J/\text{Hz} = 6.93$), 1.16 (3H, t, $J/\text{Hz} = 7.09$), 1.77–2.04 (4H, m), 2.08 (3H, s), [1.92 (3H, s; minor conformer)], 2.11 (3H, s), 2.17–2.34 (4H, m), 2.31 (3H, s) [2.33 (3H, s; minor conformer)], 3.63 (3H, s) [3.66 (3H, s; minor conformer)], 5.23 (1H, dd, $J/\text{Hz} = 9.57, 2.31$), 5.77 (1H, dd, $J/\text{Hz} = 8.25, 3.63$), [5.65 (1H, dd, $J/\text{Hz} = 7.92, 4.29$; minor conformer)], 7.08–7.28 (7H, m), 7.50 (1H, d, $J/\text{Hz} = 7.59$); IR (KBr, ν/cm^{-1}) 1761, 1290, 1258; MS (EI, 70 eV, relative intensity) m/z 485 (M^+ , 42), 310 (29), 282 (53), 222 (100). Found: m/z 485.2554. Calcd for $\text{C}_{31}\text{H}_{35}\text{NO}_4$: $M = 485.2566$; Crystal data: $\text{C}_{31}\text{H}_{35}\text{NO}_4$, $M = 485.62$, orthorhombic, $P2_12_1$ (#19), $a = 15.342(7)\text{ \AA}$, $b = 23.06(1)\text{ \AA}$, $c = 7.664(10)\text{ \AA}$, $V = 2711(4)\text{ \AA}^3$, $Z = 4.20$, $\mu = 0.82\text{ cm}^{-1}$, $R = 0.165$, $R_w = 0.183$.
- a) J. J. P. Stewart, *J. Comput. Chem.*, **10**, 209, 221 (1989). b) PM3 calculations were done on a CAChe system ver. 3.7 (CAChe Scientific, Inc.).