3128 © 1993 The Chemical Society of Japan NOTES *Bull. Chem. Soc. Jpn.*, **66**, 3128—3131(1993) [Vol. 66, No. 10

Novel Biradical Cyclization via Remote-Hydrogen Transfer in Photochemistry of 2-Dialylaminoethyl 3-Benzoylacrylates

Tadashi Hasegawa,* Yuko Yamazaki, and Michikazu Yoshioka†
Department of Chemistry, Tokyo Gakugei University, Nukuikitamachi 4-1-1, Koganei, Tokyo 184
†Department of Chemistry, Saitama University, Shimo-okubo 255, Urawa, Saitama 338

(Received May 27, 1993)

Synopsis. Upon irradiation, 2-(*N*,*N*-dibenzylamino)ethyl and 2-(*N*-benzyl-*N*-methylamino)ethyl 3-benzoylacrylate underwent photocyclization via remote-proton transfer from their (*Z*)-forms competing with (*E*)-(*Z*) isomerization. The quantum yield for the cyclization under the conditions where both (*E*)- and (*Z*)-isomers absorb the irradiation light was estimated to be 0.05 by applying the steady-state approximation.

Hydrogen abstraction through a medium-sized cyclic transition state is a quite rare event in the photochemistry of alkyl aryl ketones.[1—4] We have reported that β- and γ-oxo esters underwent photocyclization via a remote hydrogen transfer through more than nine-membered cyclic transition states,[5—8] and that in the system where both remote hydrogen abstraction and (*E*)-(*Z*) photoisomerization were possible only the later process took place.[6] We report here on novel biradical cyclization via a charge-transfer intermediate from (*Z*)-isomer in the photochemistry of 2-dialkylaminoethyl 3-benzoylacrylates **1**.

Irradiation of (***E***)-**1a** in benzene under nitrogen with a 450 W high-pressure mercury lamp through a Pyrex filter gave (***Z***)-**1a** and **2a** in 63 and 1% yields, respectively, at 77% conversion. Yields changed with conversion (Fig. 1). Irradiation of (***Z***)-**1a** under the same conditions gave (***E***)-**1a** and **2a** in 17 and 14% yields, respectively, at 55% conversion (Scheme 1). Formation of **2a** can be explained in terms of recombination of the radical center on the β-carbon, where an unpaired electron should be dense by the allylic delocalization, with that on the benzylic carbon of the biradical intermediate, formed through a remote proton migration. The expected normal cyclization product, the nine-membered azalactone, could not be detected. This might be due to lower ring strain in the seven-membered azalactone. Intramolecular trapping of ketyl radical center with a delocalized allylic radical was reported in the Type II photoreaction; however, such trapping gave a product having a larger ring than the normal cyclization product, a cyclobutanol derivative.[9] The trapping of the alkyl radical center by the delocalized allylic radical to give a product having a smaller ring than the normal cyclization product seems to be characteristic in the photocyclization via remote-hydrogen transfer through a medium-sized cyclic transition state. The photoreactions of (***E***)- and (***Z***)-**1a** occurred in both benzene and acetonitrile.

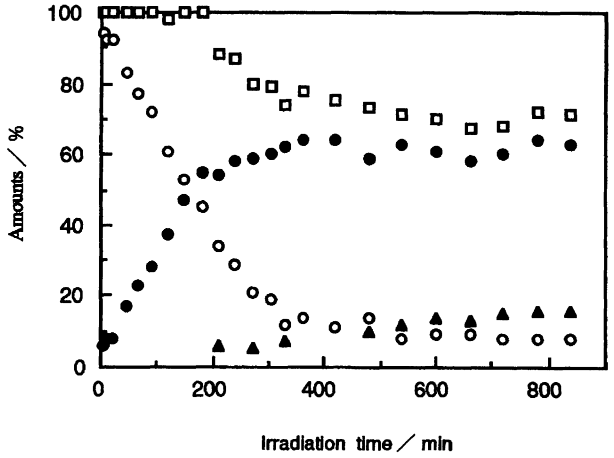
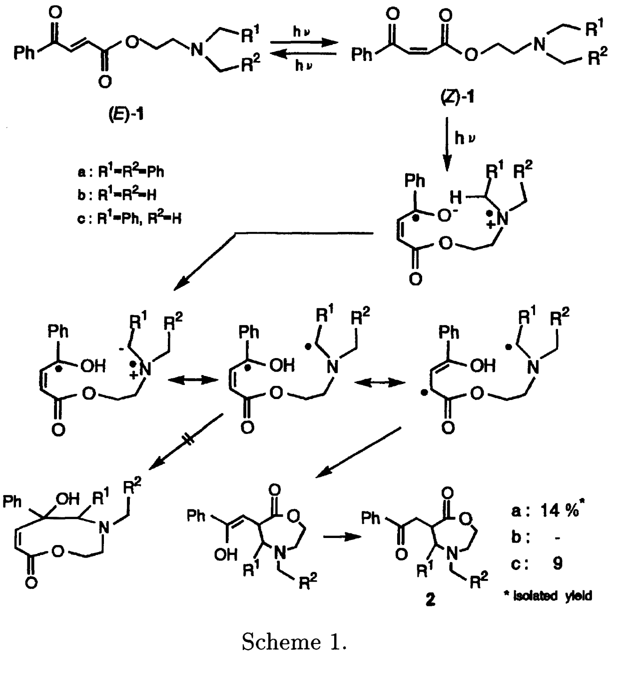


Fig. 1. Rate of disappearance of (***E***)-**1a** (○) and production of (***Z***)-**1a** (●) and **2a** (▲) as a function of irradiation time. □ : (***E***)-**1a**+(***Z***)-**1a**.

Figure 1 shows the time development of disappearance of (***E***)-**1a** and production of (***Z***)-**1a** and **2a** in acetonitrile. The formation of (***Z***)-**1a** is increased in proportion to the disappearance of (***E***)-**1a**, and the total percentage of (***E***)- and (***Z***)-**1a** is nearly 100% in the initial stage of the photoreaction of (***E***)-**1a**. Prolonged irradiation causes a decrease of the total percentage of



Scheme 1.

(***E***)- and (***Z***)-**1a** and an increase of **2a** through the ratio of (***E***)- to (***Z***)-**1a** is nearly constant. This indicates that the (*E*)–(*Z*) isomerization from (***E***)-**1a** is fast and a sole photochemical process in the initial stage of the reaction, that the (*E*)/(*Z*) ratio reaches a photostationary state, and that the conversion to **2a** occurs only from excited molecules of (***Z***)-**1a**. These results probably reflect the profitable statistical probability of approaching of an amine nitrogen to an excited carbonyl oxygen in the (*Z*)-configuration. The quenching of the isomerization and the cyclization with 2,5-dimethyl-2,4-hexadiene (about 0.1 mol dm^{-3}) or dissolved oxygen in the solvent could not be observed. These results indicate that the photoisomerization occurs faster than bimolecular quenching governed by the diffusion control and that a charge-transfer intermediate intervenes during the course from (***Z***)-**1a** to **2a** as in the cases of aminoalkyl phenyl ketones.[10)] The electron-transfer must occur only in the (*Z*)-configuration. Therefore, a simple scheme for the photochemical behavior of (***E***)-**1a** can be written as Scheme 2, where IM is an intermediate for (*E*)–(*Z*) isomerization, CT is a charge-transfer intermediate, and BR is a biradical intermediate.

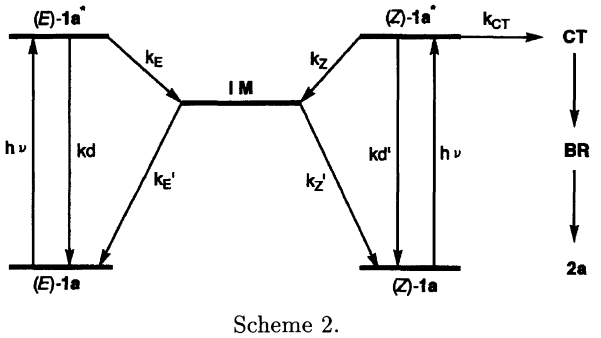
A value of $k_{\mathrm{CT}}/(k_{\mathrm{Z}}+k\mathrm{d}')$ could be estimated by applying the steady-state approximation:

$$\mathrm{d}[(\boldsymbol{Z})-\mathbf{1a}^*]/\mathrm{d}t = \varepsilon_{\mathrm{Z}}[(\boldsymbol{Z})-\mathbf{1a}]/(\varepsilon_{\mathrm{E}}[(\boldsymbol{E})-\mathbf{1a}] + \varepsilon_{\mathrm{Z}}[(\boldsymbol{Z})-\mathbf{1a}])I - (k\mathrm{d}' + k'_{\mathrm{Z}} + k_{\mathrm{CT}})[(\boldsymbol{Z})-\mathbf{1a}^*] = 0 \tag{1}$$

$$\mathrm{d}[\mathbf{2a}]/\mathrm{d}t = k_{\mathrm{CT}}[(\boldsymbol{Z})-\mathbf{1a}^*] = \{k_{\mathrm{CT}}/(k\mathrm{d}' + k_{\mathrm{Z}} + k_{\mathrm{CT}})\}\ \{\varepsilon_{\mathrm{Z}}[(\boldsymbol{Z})-\mathbf{1a}]/(\varepsilon_{\mathrm{E}}[(\boldsymbol{E})-\mathbf{1a}] + \varepsilon_{\mathrm{Z}}[(\boldsymbol{Z})-\mathbf{1a}])\}\cdot I \tag{2}$$

$$[\mathbf{2a}] = \{k_{\mathrm{CT}}/(k\mathrm{d}' + k'_{\mathrm{Z}} + k_{\mathrm{CT}})\}\ \{\varepsilon_{\mathrm{Z}}[(\boldsymbol{Z})-\mathbf{1a}]/(\varepsilon_{\mathrm{E}}[(\boldsymbol{E})-\mathbf{1a}] + \varepsilon_{\mathrm{Z}}[(\boldsymbol{Z})-\mathbf{1a}])\cdot It \tag{3}$$

The value of $k_{\mathrm{CT}}/(k\mathrm{d}'+k_{\mathrm{Z}}+k_{\mathrm{CT}})$ can be obtained as 0.05 as a slope for the linear relationship between [**2a**] and $\{\varepsilon_{\mathrm{Z}}[(\boldsymbol{Z})-\mathbf{1a}]/(\varepsilon_{\mathrm{E}}[(\boldsymbol{E})-\mathbf{1a}]+\varepsilon_{\mathrm{Z}}[(\boldsymbol{Z})-\mathbf{1a}])\}\cdot It$ (Fig. 2). The value of $k_{\mathrm{CT}}/(k\mathrm{d}'+k_{\mathrm{Z}})$ was estimated to be 0.05.



Scheme 2.

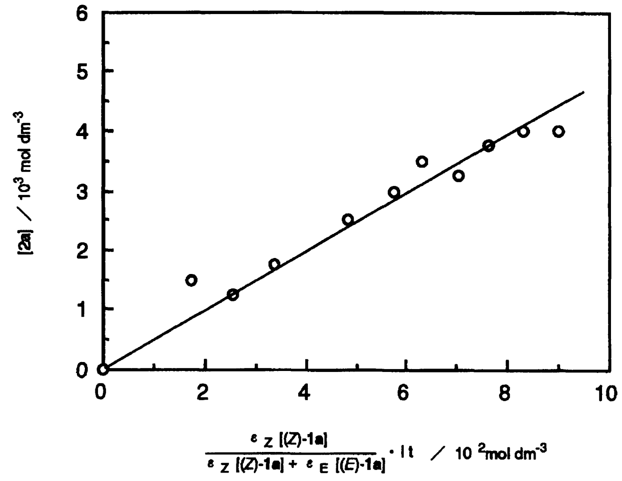


Fig. 2. Plots of amount of **2a** formed vs. light intensity absorbed by (***Z***)-**1a**. The light intensity of 313 nm line was determined to be 1.15×10^{-4} mol dm^{-3} min^{-1} by using valerophenone actinometer; $\varepsilon_{\mathrm{E}}=0.24$, $\varepsilon_{\mathrm{Z}}=0.39$.

Values of quantum yields for production of **2a** from (***Z***)-**1a**, calculated by direct comparison of its chemical yield with that of acetophenone from valerophenone actinometer, were not constant and changed with conversion of **1a** because both cis and trans isomers absorbed the irradiating light. Therefore, the observed quantum yields are not the true quantum yield. The value of 0.05 obtained from the above procedure should be the true quantum yield for production of **2a** from (***Z***)-**1a**.

Irradiation of 2-(*N*-benzyl-*N*-methylamino)ethyl ester (***E***)-**1c** under the same conditions also gave **2c**, produced via remote benzylic hydrogen transfer, in 9% yield together with 2-(*N*-benzyl-*N*-methyl)ethyl 3-benzoylpropinate[8)] (27%). No cyclization product via methyl hydrogen transfer could be obtained in this case. The formation of the propionate can be explained in terms of photoreaction via intermolecular hydrogen migration from the amino group of a **1c** molecule to carbonyl oxygen of another **1c** molecule. On the other hand, irradiation of *N*,*N*-dimethylaminoethyl ester (***E***)-**1b** gave an intractable mixture. Photocyclization through a remote-hydrogen transfer must require stable radical centers, such as a benzyl radical center, in a biradical intermediate. When a stable radical center cannot be formed, a process other than photocyclization might take place.

Experimental

The IR spectra were recorded with a JASCO IR Report-100 spectrometer, the ^{1}H and ^{13}C NMR spectra were measured with a JEOL FX90Q or Bruker AM400 spectrometer using tetremethylsilane as an internal standard. An Ushio 450 W high-pressure mercury lamp was used as an irradiation source. The 3-benzoylacrylates (***E***)-**1a**-**c** were prepared by esterification of 3-benzoylacrylic acid and the corresponding amino alcohol. The (*Z*)-isomer (***Z***)-**1a** was prepared by photolysis of (*E*)-**1a**.

2-(*N*,*N*-Dibenzylamino)ethyl (*E*)-3-Benzoylacrylate ((*E*)-1a): Mp 52.5—53.5 °C (from a mixture of benzene and hexane) ; IR (KBr) 1720 and 1660 cm^{-1}; ^{1}H NMR (CDCl$_3$) δ=2.80 (2H, t, J=5.3 Hz, NCH$_2$), 3.66 (4H, s, CH$_2$Ph), 4.31 (2H, t, J=5.3 Hz, OCH$_2$), 6.83 (1H, d, J=14.6 Hz, olefinic), 7.1—7.6 (13H, m, aromatic), 7.79 (1H, d, J=14.6 Hz, olefinic), and 7.8—8.0 (2H, m, aromatic). Found: C, 78.34; H, 6.39; N, 3.40%. Calcd for $C_{26}H_{25}O_3N$: C, 78.17; H, 6.31; N, 3.51%.

2-(*N*,*N*-Dibenzylamino)ethyl (*Z*)-3-Benzoylacrylate ((*Z*)-1a): Yellow oil;[11] IR (neat) 1720 and 1670 cm^{-1}; ^{1}H NMR (CDCl$_3$) δ=2.56 (2H, t, J=6 Hz, NCH$_2$), 3.52 (4H, s, CH$_2$Ph), 4.06 (2H, t, J=6.2 Hz, OCH$_2$), 6.20 (1H, d, J=11.9 Hz, olefinic), 6.82 (1H, d, J=11.9 Hz, olefinic), 7.1—7.5 (13H, m, aromatic), and 7.7—7.9 (2H, m, aromatic).

2-(*N*,*N*-Dimethylamino)ethyl (*E*)-3-Benzoylacrylate ((*E*)-1b): Yellow oil;[11] IR (neat) 1720 and 1670 cm^{-1}; ^{1}H NMR (CDCl$_3$) δ=2.30 (6H, s, CH$_3$), 2.63 (2H, t, J=8.5 Hz, NCH$_2$), 4.31 (2H, t, J=8.5 Hz, OCH$_2$), 6.84 (1H, d, J=15.4 Hz, olefinic), 7.2—7.6 (3H, m, aromatic), 7.86 (1H, d, J=15.4 Hz, olefinic), and 7.9—8.0 (2H, m, aromatic).

2-(*N*-Benzyl-*N*-methylamino)ethyl (*E*)-3-Benzoylacrylate ((*E*)-1c): Yellow oil;[11] IR (neat) 1720 and 1670 cm^{-1}; ^{1}H NMR (CDCl$_3$) δ=2.31 (3H, s, CH$_3$), 2.73 (2H, t, J=5.8 Hz, NCH$_2$), 3.58 (2H, s, CH$_2$Ph), 4.36 (2H, t, J=5.8 Hz, OCH$_2$), 6.88 (1H, d, J=15.4 Hz, olefinic), 7.1—7.6 (8H, m, aromatic), 7.89 (1H, d, J=15.4 Hz, olefinic), and 7.9—8.0 (2H, m, aromatic+olefinic).

General Procedure for Preparative Photolysis of 1. A benzene solution of **1** was irradiated under nitrogen with a 450 W high-pressure mercury lamp through a Pyrex filter. After the solvent was removed, the residue was chromatographed on a silica-gel column. Elution with a mixture of benzene and ethyl acetate gave unreacted **1**, the corresponding isomer, and **2**. In the case of photolysis of **1c** an propionate was also obtained.

4-Benzyl-2-phenacyl-3-phenyl-4-aza-6-hexanolide (2a): Mp 166—167 °C (from a mixture of benzene and hexane); IR (KBr) 1730 and 1670 cm^{-1}; ^{1}H NMR (CDCl$_3$) δ=2.36 (1H, dd, J=4.0 and 17.8 Hz, CH$_2$COPh), 2.82 (1H, ddd, J=4.0, 11.9, 13.8 Hz, 5-H), 3.01 (1H, dt, J=13.8 and 4.0 Hz, 5-H), 3.29 (1H, d, J=13.8 Hz, CH$_2$Ph), 3.57 (1H, d, J=13.8 Hz, CH$_2$Ph), 3.67 (1H, dd, J=9.9 and 17.8 Hz, CH$_2$COPh), 3.73 (1H, d, J=9.9 Hz, 3-H), 4.13 (1H, dt, J=4.0 and 9.9 Hz, 2-H), 4.38 (1H, ddd, J=4.0, 4.0, and 11.9 Hz, 6-H), 4.63 (1H, ddd, J=4.0, 11.9, and 11.9 Hz, 6-H), and 7.3—7.8 (15H, m, aromatic); ^{13}C NMR (CDCl$_3$) δ=40.1 (t), 43.8 (d), 50.2 (t), 59.3 (t), 65.1 (t), 67.0 (d), 127.3 (d), 128.0 (d, 4C), 128.4 (d, 4C), 128.6 (d), 128.8 (d, 2C), 129.0 (d, 2C), 129.5 (s, 2C), 132.9 (d), 138.4 (s), 174.5 (s), and 197.5 (s). Found: C, 78.30; H, 6.42; N, 3.38%. Calcd for $C_{26}H_{25}O_3N$: C, 78.17; H, 6.31; N, 3.51%.

4-Methyl-2-phenacyl-3-phenyl-4-aza-6-hexanolide (2c): Mp 191—192 °C (from a mixture of benzene and hexane); IR (KBr) 1730 and 1675 cm^{-1}; ^{1}H NMR (CDCl$_3$) δ=2.22 (3H, s, CH$_3$), 2.76 (1H, ddd, J=2.1, 4.6, and 14.7 Hz, 6-H), 2.77 (1H, dd, J=5.9, and 17.7 Hz, CH$_2$CO), 3.29 (1H, ddd, J=3.1, 10.0, and 14.7 Hz, 5-H), 3.44 (1H, dd, J=7.2 and 17.7 Hz, CH$_2$CO), 3.82 (1H, d, J=3.9 Hz, 3-H), 4.08 (1H, ddd, J=3.9, 5.9, and 7.2 Hz, 2-H), 4.37 (1H, ddd, J=3.1, 4.6, and 13.4 Hz, 6-H), 4.77 (1H, ddd, J=2.1, 10.0, and 13.4 Hz, 6-H), 7.1—7.5 (8H, m, aromatic), and 7.7—7.8 (2H, m, aromatic); ^{13}C NMR (CDCl$_3$) δ=39.6 (t), 43.4 (d), 43.8 (q), 52.0 (t), 67.6 (t), 69.0 (d), 128.1 (d, 2C), 128.2 (d, 2C), 128.5 (d, 4C), 129.5 (d), 133.1 (d), 135.8 (s), 137.1 (s), 174.5 (s), and 197.5 (s). Found: C, 73.97; H, 6.53; N, 4.19%. Calcd for $C_{20}H_{21}O_3N$: C, 74.28; H, 6.55; N, 4.33%.

Rate Determination of Photoreaction of 1a. The acrylate (***E***)-**1a** was dissolved in acetonitrile (0.05 mol dm^{-3}) and 5 cm^3 portions of the solution were placed in 150×15 mm Pyrex culture tubes. The tubes were stoppered and irradiated. Irradiation was done on a "merry-go-round" apparatus with an Ushio 450 W high-pressure mercury lamp. Potassium chromate filter solution was used to isolate the 313 nm line.[12] After the irradiation, an acetonitrile solution containing a knows amount of phenanthrene, as a calibrant, was added to the solution. Analyses of the starting ester and products were done using a Gasukuro Kogyo 570B high-pressure liquid chromatograph with a Model 511 single-wave UV detector (254 nm). An Inertsil ODS-2 column (4.6×150 mm) was used, and a mixture of acetonitrile–water (v/v=7/3) was used as the moving phase at a flow rate of 8 cm^3 min^{-1}.

References

1) N. A. J. Carless and G. K. Fekarurhobo, *Tetrahedron Lett.*, **25**, 5943 (1984); M. A. Meader and P. J. Wagner, *J. Org. Chem.*, **50**, 419 (1985); B. Zhou and P. J. Wagner, *J. Am. Chem. Soc.*, **111**, 6796 (1989).

2) H. A. J. Carless and S. M-Kibende, *J. Chem. Soc., Chem. Commun.*, **1987**, 1673; G. Adam, A. Preiss, P. D. Hung, and L. Kutschabsky, *Tetrahedron*, **43**, 5815 (1987).

3) The hydrogen abstraction from long alkyl tails of *n*-alkyl *p*-benzoylbenzoate through a large-sized cyclic transition state has been reported: R. Breslow, S. Baldwin, T. Flechthner, P. Kalicky, S. Liu, and W. Washburn, *J. Am. Chem. Soc.*, **95**, 3251 (1973); M. A. Winnik, R. E. Trueman, G. Jackouski, D. S. Saunders, and S. G. Whittington, *J. Am. Chem. Soc.*, **96**, 4843 (1974); K. Orito, M. Ohti, and H. Suginome, *J. Chem. Soc., Chem. Commun.*, **1990**, 1074, and references cited therein.

4) Some phthalimides undergo photocyclization through a remoteproton migration from their charge-transfer state: Y. Kanaoka, *Acc. Chem. Res.*, **11**, 407 (1978); M. Wada, H. Nakai, Y. Sata, Y. Hatanaka, and Y. Kanaoka, *Tetrahedron*, **39**, 2691 (1983), and references cited therein.

5) T. Hasegawa, Y. Horikoshi, S. Iwata, and M. Yoshioka, *J. Chem. Soc., Chem. Commun.*, **1991**, 1617.

6) T. Hasegawa, K. Takashima, H. Aoyama, and M. Yoshioka, *Bull. Chem. Soc. Jpn.*, **65**, 3498 (1992).

7) T. Hasegawa, T. Ogawa, K. Miyata, A. Karakizawa, M. Komiyama, K. Nishizawa, and M. Yoshioka, *J. Chem. Soc., Perkin Trans. 1*, **1990**, 901.

8) T. Hasegawa, K. Mukai, K. Mizukoshi, and M. Yoshioka, *Bull. Chem. Soc. Jpn.*, **63**, 3348 (1990).

9) For examples: A. Padwa and D. Eastman, *J. Am. Chem. Soc.*, **93**, 6292 (1971); R. A. Cormier and W. C. Agosta, *J. Am. Chem. Soc.*, **96**, 1867 (1974); H. Morrison, V. Tisdale, P. J. Wagner, and K-C. Liu, *J. Am. Chem. Soc.*,

97, 7189 (1975).

10) S. G. Cohen, A. Parola, and G. H. Parsons, Jr., *Chem. Rev.*, **73**, 141 (1973); G. J. Kavarnos and N. J. Turro, *Chem. Rev.*, **86**, 401 (1986).

11) The (*Z*)-isomer (***Z***)-**1a** changed to the (*E*)-isomer by heating. The compounds (***E***)-**1b** and (***E***)-**1c** were partially decomposed by distillation under reduced pressure.

12) S. L. Murov, "Handbook of Photochemistry," Marcel Dekker, New York (1973), p. 99.