Solvent Dependent Photochemical Reactions of 3-(2-Alkylphenyl)-2,2-dimethyl-3-oxopropanoates and Their Related Compounds

Masaichi Saito, Yumiko Kamei, Kanae Kuribara, and Michikazu Yoshioka*

Department of Chemistry, Faculty of Science, Saitama University Shimo-ohkubo, Urawa, Saitama 338-8570, Japan

Tadashi Hasegawa

Department of Chemistry, Tokyo Gakugei University Nukuikitamachi, Koganei, Tokyo 184-0015, Japan

Received July 22, 1998

Photochemical reactions of methyl 3-(*o*-alkylphenyl)-2,2-dimethyl-3-oxopropanoates in hexane gave only the corresponding benzocyclobutenols. However, when irradiation was carried out in methanol, 3-oxonaphthalenones were produced together with the benzocyclobutenols. The ratio of benzocyclobutenol to naphthalenone depends on the bulkiness of the alkyl group in the ortho position. Intermediary 1,4-diradicals or dienols were efficiently trapped by oxygen to afford the corresponding peroxides and/or oxygenated compounds derived from the peroxides.

Introduction

The photochemistry of *o*-alkylphenyl ketones has been widely explored for a few decades, and a number of comprehensive reviews have been published.[1] The triplet states of these ketones are transformed into diradicals via intramolecular hydrogen abstraction, which decay to short-lived *Z*- and long-lived *E*-dienols. The former undergo a very rapid 1,5-hydrogen shift to regenerate the starting ketone, while the latter cyclize to give the benzocyclobutenols.[2] It is well-known that the benzocyclobutenols from *o*-alkylphenyl ketones are thermally unstable and convert quantitatively to the parent ketone by heating via the dienol as evidenced by trapping experiments.[3] On the other hand, photochemical reactions of 2,6-dialkylphenyl ketones give benzocyclobutenols efficiently because the large steric congestion in the triplet diradical results in cyclization rather than the sterically unfavorable enolization.[4] Contrary to the extensively studied *o*-alkylphenyl ketones, the photochemistry of *o*-alkylphenyl 1,3-diketones is still less explored.[5] Irradiation of some *o*-alkylphenyl 1,3-diketones in methanol gave naphthalenone derivatives exclusively instead of benzocyclobutenols.[6] However, irradiation of *o*-alkylphenyl *β*-keto esters having no substituents on the alpha position did not afford any isolable photoproducts,[6] though they produce dienols upon irradiation, as evidenced by deuterium incorporation.[7]

We have already reported that 1-(*o*-methylphenyl)-2,2-dimethyl 1,3-diketones underwent photocyclization in hexane to afford benzocyclobutenols efficiently because the reverse transfer of hydrogen in the intermediary 1,4-diradicals to reproduce the starting ketones was suppressed owing to intramolecular hydrogen bonding.[8,9] We also reported on the photochemical reactions of *β*-hydroxy ketones in which *β*-hydrogen abstraction occurred competitively with *γ*-hydrogen abstraction.[10] Because of our interest in the effect of *β*-functional groups on the photoreactivity of *o*-alkylaryl ketones, we now report novel selective photochemical reactions of 3-(2-alkylphenyl)-2,2-dimethyl-3-oxopropanoates and their related compounds having an amide group in the *β*-position. Furthermore, the effect of the bulkiness of the ortho and ester alkyl groups on photoreactivities is reported.

Results and Discussion

Synthesis of 3-(*o*-Alkylphenyl)-3-oxo Esters and Amides. The 3-(2-methylphenyl)-2,2-dimethyl-3-oxopro-

(1) (a) Sammes, P. G. *Tetrahedron* **1976**, *32*, 405. (b) Wagner, P. J. *Pure Appl. Chem.* **1977**, *49*, 259. (c) Wagner, P. J. In *Rearrangements in Ground and Excited States*; de Mayo, P., Ed.; Academic Press: New York, 1980; Vol. 3, p 381. (d) Scaiano, J. C. *Acc. Chem. Res.* **1982**, *15*, 252.

(2) Wagner, P. J.; Subrahmanyam, D.; Park, B.-S. *J. Am. Chem. Soc.* **1991**, *113*, 709.

(3) (a) Arnold, B. J.; Sammes, P. G.; Wallace, T. W. *J. Chem. Soc., Perkin Trans. 1* **1974**, 409. (b) Arnold, B. J.; Sammes, P. G.; Wallace, T. W. *J. Chem. Soc., Perkin Trans. 1* **1974**, 415.

(4) (a) Matsuura, T.; Kitaura, Y. *Tetrahedron Lett.* **1967**, *34*, 3309. (b) Matsuura, T.; Kitaura, Y. *Tetrahedron* **1969**, *25*, 4487. (c) Ito, Y.; Umehara, Y.; Hijiya, T.; Yamada, Y.; Matsuura, T. *J. Am. Chem. Soc.* **1980**, *102*, 5917. (d) Ito, Y.; Nishimura, H.; Umehara, Y.; Yamada, Y.; Tone, M.; Matsuura, T. *J. Am. Chem. Soc.* **1983**, *105*, 1590. (e) Guérin, B.; Johnson, L. J. *Can. J. Chem.* **1989**, *67*, 473.

(5) In contrast to 1,3-diketones, hydrogen abstraction by the triplet states of 1,2-diketones has received relatively much attention over the past two decades. For examples of very recent reports for the photochemistry of 1,2-diketones, see: (a) Wagner, P. J.; Park, B.-S.; Sobczak, M.; Frey, J.; Rappoport, Z. *J. Am. Chem. Soc.* **1995**, *117*, 7619. (b) Hasegawa, T.; Imada, M.; Imase, M.; Yamazaki, Y.; Yoshioka, M. *J. Chem. Soc., Perkin Trans. 1* **1997**, 1271.

(6) Hornback, J. M.; Poundstone, M. L.; Vadlamani, B.; Graham, S. M.; Gabay, J.; Patton, S. T. *J. Org. Chem.* **1988**, *53*, 5597.

(7) *β*-Keto esters have been reported to undergo the Norrish type II reaction, see: Hasegawa, T.; Arata, Y.; Endoh, M.; Yoshioka, M. *Tetrahedron* **1985**, *41*, 1667.

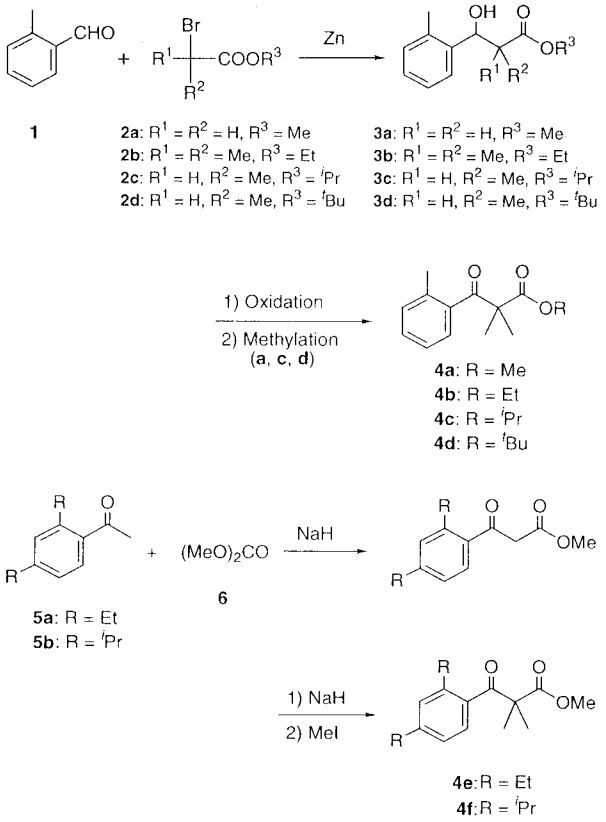
(8) (a) Yoshioka, M.; Arai, M.; Nishizawa, K.; Hasegawa, T. *J. Chem. Soc., Chem. Commun.* **1990**, 374. (b) Yoshioka, M.; Nishizawa, K.; Arai, M.; Hasegawa, T. *J. Chem. Soc., Perkin Trans. 1* **1991**, 541. (c) Yoshioka, M.; Momose, S.; Nishizawa, K.; Hasegawa, T. *J. Chem. Soc., Perkin Trans. 1* **1992**, 499.

(9) Solvation of a hydroxy radical results in the enhancement of the quantum efficiency with which valerophenone undergoes photoelimination in solution. Wagner, P. J. *J. Am. Chem. Soc.* **1967**, *89*, 5898.

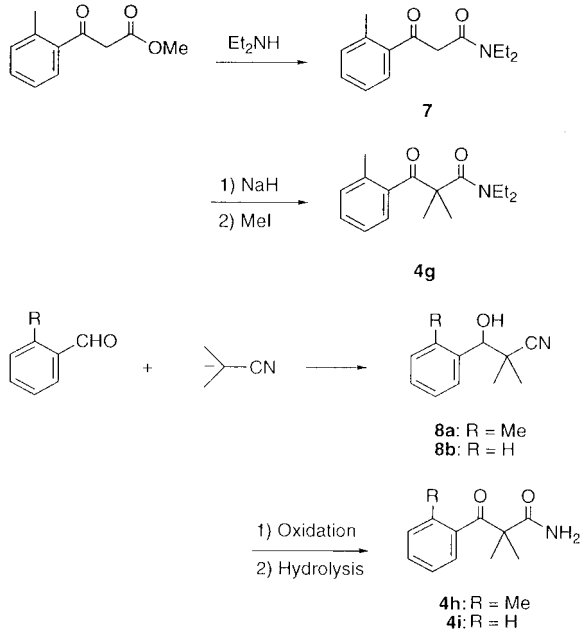
(10) (a) Yoshioka, M.; Miyazoe, S.; Hasegawa, T. *J. Chem. Soc., Chem. Commun.* **1992**, 418. (b) Yoshioka, M.; Miyazoe, S.; Hasegawa, T. *J. Chem. Soc., Perkin Trans. 1* **1993**, 2781.

10.1021/jo981433b CCC: $15.00
Published on Web 11/10/1998

Scheme 1



Scheme 2



panoates **4a**−**d** were prepared by the Reformatsky reaction of *o*-tolualdehyde (**1**) with 2-bromoalkanoates **2** followed by Jones oxidation and methylation. The 3-(2,4-dialkylphenyl)-3-oxo esters **4e** and **4f** were obtained via the condensation of the corresponding substituted acetophenones **5a** and **5b** with dimethyl carbonate **6** followed by methylation.

N,*N*-Diethyl-3-(2-methylphenyl)-2,2-dimethyl-3-oxopropanamide (**4g**) was prepared in a poor yield from the corresponding β-keto amide **7**. 3-(2-Methylphenyl)-2,2-dimethyl-3-oxopropanamide (**4h**) and 3-phenyl-2,2-dimethyl-3-oxopropanamide (**4i**) were synthesized by hydrolysis of the corresponding β-keto nitriles **8**.

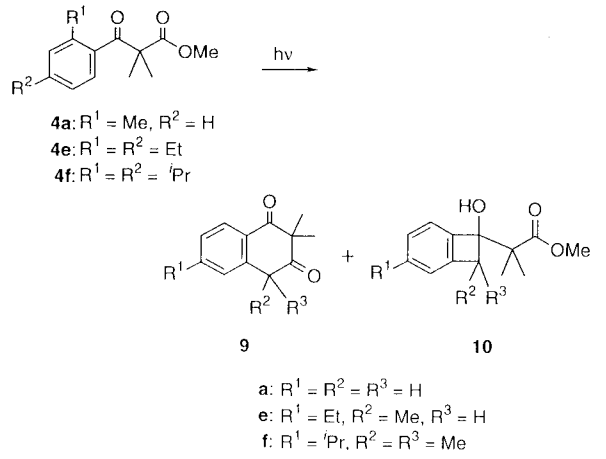
Irradiation of Methyl 3-(2-Alkylphenyl)-2,2-dimethyl-3-oxopropanoates: Effect of Bulkiness of Ortho Alkyl Substituents on Photoreactivities. Irradiation of methyl 3-*o*-tolyl-2,2-dimethyl-3-oxopropanoate (**4a**) in methanol with a high-pressure mercury lamp through a Pyrex filter gave the oxonaphthalenone **9a** (23%) as the major product together with the benzocyclobutenol **10a** (9%) at 94% conversion, in contrast to Hornback's report that naphthalenone derivatives were obtained exclusively in the photochemical reactions of *o*-tolyl 1,3-diketones in methanol.[6] The yields of photoproducts **9** and **10** are given in Table 1. The benzocyclobutenol **10a** is probably formed from the *E*-enol resulting from an intermediary triplet diradical.[2] The formation of **9a** is rationalized in terms of intramolecular trapping of the benzyl radical moiety by the ester carbonyl carbon followed by hydrogen shift and elimination of methanol[8b] or by cyclization of the *E*-enol.[6] We have already found that naphthalenone derivatives were obtained as major products in the photochemical reactions of 3-alkyl and 3-aryl-substituted 1-*o*-tolyl-2,2-dimethyl 1,3-diketones in methanol together with benzocyclobutenols.[8b] In the present case, however, the product ratio of **10a** to **9a** is higher than those of the previous results observed in *o*-tolyl 1,3-diketones, probably due to the less electrophilic nature of ester carbon moiety in **4a**. Irradiation of the 3-*o*-ethylphenyl-3-oxo ester **4e** under the same conditions gave the naphthalenone **9e** and the benzocyclobutenol **10e** in 25 and 32% yields, respectively. On the other hand, photochemical reaction of the β-keto ester **4f** bearing an isopropyl group in the ortho position in methanol exclusively afforded benzocyclobutenol **10f** (100%). Thus, the ratio of the naphthalenone **9** to the benzocyclobutenol **10** became lower with the bulkier ortho alkyl group, reflecting the steric hindrance leading to **9**. Contrary to the photoreactions of **4a**,**e**,**f** in methanol, irradiation of them in hexane gave benzocyclobutenols **10a**,**e**,**f** exclusively, as was observed in our previous reports.[8,10]

Table 1. Yields of Photoproducts in the Photoreactions of β-Keto Esters

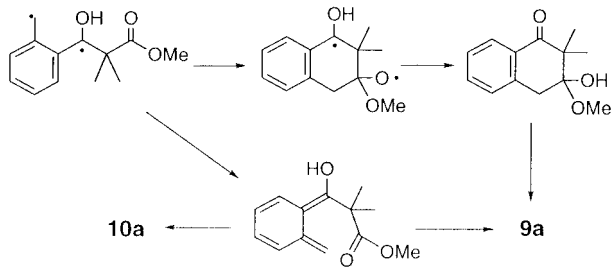
		yields (%)	
β-keto ester	solvent	**9**	**10**
4a	methanol	23	9
4e	methanol	25	32
4f	methanol		100
4a	hexane		70
4e	hexane		82
4f	hexane		73

Irradiation of Various Alkyl Esters of 3-(2-Methylphenyl)-2,2-dimethyl-3-oxopropanoic Acids: Effect of Bulkiness of the Ester Group on Product Distribution. Effect of bulkiness of the ester group on product distribution was also investigated. Irradiation of the ethyl **4b**, isopropyl **4c** and *tert*-butyl **4d** esters of 3-(2-methylphenyl)-2,2-dimethyl-3-oxopropanoic acid in methanol gave benzocyclobutenols **10b** (11%), **10c** (35%), and **10d** (69%), respectively, along with the naphthalenone **9a** (27% from **4b**, 15% from **4c**, and 3% from **4d**), reflecting perhaps the less favorable reaction of the benzyl radical site with the ester carbonyl carbon having the bulky alkyl group because of the sterically repulsive interaction.

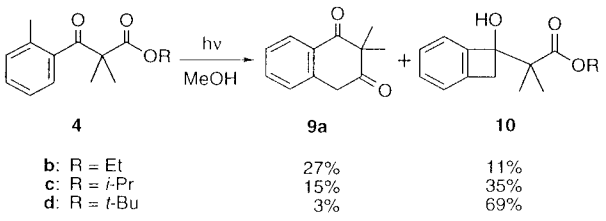
Scheme 3



Scheme 4

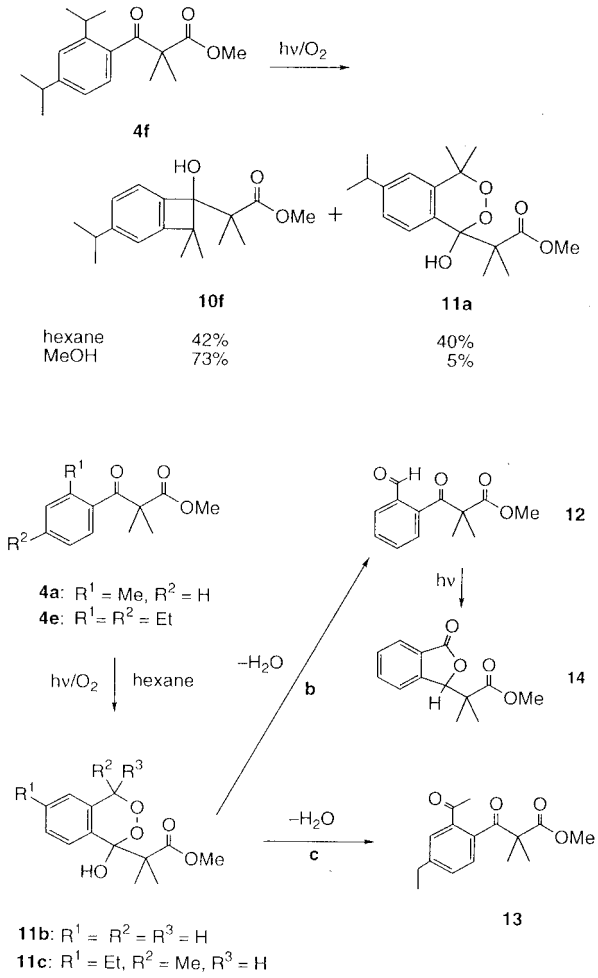


Scheme 5



Irradiation of Methyl 1-(*o*-Alkylphenyl)-2,2-dimethyl-3-oxopropanoates in the Presence of Oxygen. Irradiation of **4f** in hexane under air-bubbling gave the peroxide **11a** (40%) and the benzocyclobutenol **10f** (42%) at 52% conversion. Although the formation of **11a** is reasonably explained by the reaction of the intermediate 1,4-diradical or dienol with oxygen,[11,12] it is still ambiguous whether the oxidation involves the triplet-state dienol or the ground-state dienol.[13] Interestingly, the oxidation was effectively suppressed [**10f** (73%), **11a** (5%)] in methanol probably due to solvation of the intermediate by methanol to protect it from oxygen, while

Scheme 6



in hexane oxygen has more access to the intermediate because of intermolecular hydrogen bonding. This type of remarkable solvent effect has not been reported in irradiation of *o*-alkylphenyl ketones in the presence of oxygen. Photooxidation of the *o*-alkylphenyl ketones proceeds in both methanol and hexane.[11a,14]

In the photochemical reactions of **4a** and **4e** in hexane under air-bubbling, intermediary peroxides **11b** and **11c** readily underwent dehydration to give the aldehyde **12** and the ketone **13**, respectively. The aldehyde **12** underwent further reaction to yield the phthalide **14** under the irradiation conditions.[12]

Photochemical Reactions of 3-(2-Methylphenyl)-2,2-dimethyl-3-oxopropanamides. The photochemistry of *o*-tolyl β-oxopropanamides has also been a subject of interest. *N*-Alkyl β-oxo amides are known to undergo photocyclization through hydrogen shift from the carbon next to the nitrogen to the ketone carbonyl oxygen.[15] In the course of our study on the effect of β-functionality on the photoreactions of *o*-alkylphenyl ketones, we chose an *N*,*N*-disubstituted 3-oxopropanamide **4g** because of the presence of two kinds of hydrogens abstractable by the ketone carbonyl oxygen: one is the γ-hydrogen in the 2-methylphenyl group and the other is the δ-hydrogen on the carbon next to the nitrogen.

(11) For example, see: (a) Kitaura, Y.; Matsuura, T. *Tetrahedron* **1971**, *27*, 1597. (b) Lutz, H.; Breheret, E.; Lindqvist, L. *J. Chem. Soc., Faraday Trans. 1* **1973**, *69*, 2096. (c) Findlay, D. M.; Tchir, M. F. *J. Chem. Soc., Faraday Trans. 1* **1976**, *72*, 1096. (d) Haag, R.; Wirz, J.; Wagner, P. J. *Helv. Chim. Acta* **1977**, *60*, 2595. (e) Small, R. D., Jr.; Scaiano, J. C. *J. Am. Chem. Soc.* **1977**, *99*, 7713. (f) Viriot-Villaume, M.-L.; Carré, M.-L.; Caubère, P. *J. Chem. Soc., Perkin Trans. 1* **1979**, 1395. (g) Carré, M.-L.; Viriot-Villaume, M.-L.; Caubère, P. *J. Chem. Soc., Perkin Trans. 1* **1979**, 2542.

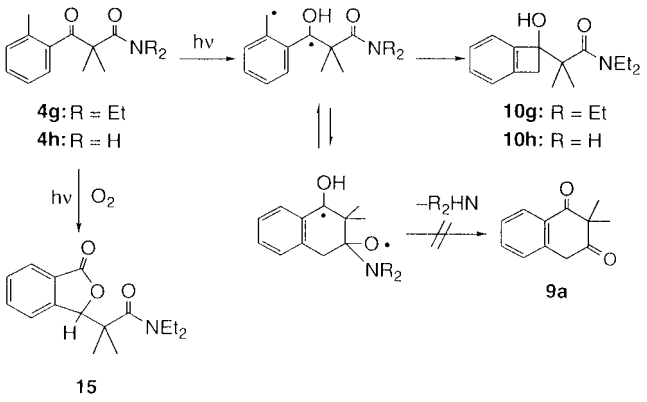
(12) We have already reported similar photochemical reactions in the presence of oxygen, see: Yoshioka, M.; Nishizawa, K.; Suzuki, J.; Iwata, Y.; Kumakura, S.; Hasegawa, T. *J. Chem. Soc., Perkin Trans. 1* **1995**, 3097.

(13) In the absence of light, dienols derived from benzocyclobutenols by heating are known to react with oxygen. (a) Yang, N. C.; Rivas, C. *J. Am. Chem. Soc.* **1961**, *83*, 2213. (b) Heindel, N. D.; Sarver, E. W.; Pfau, M. *Tetrahedron Lett.* **1968**, 3579. (c) Porter, G.; Tchir, M. F. *J. Chem. Soc. A* **1971**, 3772. (d) Pfau, M.; Sarver, E. W.; Heindel. N. D. *Bull. Soc. Chim. Fr.* **1973**, 183.

(14) For example, see: Ito, Y.; Matsuura, T. *J. Am. Chem. Soc.* **1983**, *105*, 5237, and references therein.

(15) The photochemical reactions of *N*,*N*-disubstituted benzoylacetamide, see: (a) Hasegawa, T.; Aoyama, H.; Omote, Y. *J. Chem. Soc., Perkin Trans. 1* **1976**, 2054. (b) Hasegawa, T.; Aoyama, H.; Omote, Y. *J. Chem. Soc., Perkin Trans. 1* **1979**, 963.

Scheme 7



Irradiation of *N*,*N*-diethyl 3-(2-methylphenyl)-2,2-dimethyl-3-oxopropanamide (**4g**) in methanol exclusively furnished the corresponding benzocyclobutenol **10g**, reflecting the preference of hydrogen abstraction from γ to δ because of the more negative entropy of activation in the six-membered ring than that in the seven-membered ring transition state.[15] In the presence of oxygen, the phthalide **15** was obtained together with the benzocyclobutenol **10g**. The phthalide **15** must be formed from the initially formed peroxide.[8b,13]

The photochemistry of the parent 3-oxopropanamides was also investigated. Irradiation of 3-(2-methylphenyl)-2,2-dimethyl-3-oxopropanamide **4h** in methanol gave the benzocyclobutenol **10h** exclusively through the abstraction of hydrogen from the *o*-methyl group. In the photoreaction of **4g** and **4h**, however, the naphthalenone **9a** was not produced, in contrast to that of methyl 3-(2-methylphenyl)-2,2-dimethyl-3-oxopropanoate (**4a**), perhaps due to the reduced ability of the amino group as a leaving group compared to the methoxy group. Finally, the photolysis of 3-phenyl-2,2-dimethyl-3-oxopropanamide **4i** resulted in a complex mixture, in which no identifiable product was obtained.

In conclusion, the photochemical reactions of 3-(2-alkylphenyl)-2,2-dimethyl-3-oxopropanoates gave two types of products, benzocyclobutenols and 3-oxonaphthalenones. The product ratio depends on the bulkiness of both 2- and ester alkyl groups as well as solvent polarity. Photooxidation of these esters proceeds more efficiently in hexane than in methanol. These novel selectivities are worthy to note not only from the mechanistic but also from a synthetic point of view. In the photolysis of 3-(2-methylphenyl)-2,2-dimethyl-3-oxopropanamides, 1,4-cyclization occurs in preference to 1,5-cyclization.

Experimental Section

General Procedure. All irradiations were carried out by using a 100 W or a 450 W high-pressure mercury lamp. ^{1}H NMR (400, 200 MHz) and ^{13}C NMR (100, 50 MHz) spectra were recorded in $CDCl_3$ with tetramethylsilane as an internal standard. IR spectra were recorded for solutions in CCl_4. Wet column chromatography (WCC) was carried out with Merck Kieselgel 60. Melting points were uncorrected and boiling points were estimated from the oven temperature in Kugelrohr distillation.

Preparation of β-Oxo Esters 4a−d. Compounds **4a**−**d** were prepared via the Reformatsky reaction. A benzene (16 mL) solution of *o*-tolualdehyde (**1**) (5.75 mL, 49.7 mmol) and methyl bromoacetate (**2a**) (4.70 mL, 49.6 mmol) was added to zinc powder (4.58 g, 70.1 mmol) in refluxing benzene (10 mL). After 5 h of refluxing, the mixture was poured into aqueous 20% sulfuric acid and extracted with ether. The ethereal extract was washed successively with saturated sodium chloride and sodium hydrogencarbonate solutions and dried over anhydrous magnesium sulfate. After the volatile substances were removed, the resulting crude hydroxy ester **3a** was dissolved in acetone (30 mL). To this solution was added dropwise 13 mL of 2.67 M Jones reagent at 5 °C, and the mixture was allowed to stand overnight. After the acetone was removed, the residue was extracted with ether. The ethereal solution was washed with sodium hydrogencarbonate solution. After the ether was removed, the residue was chromatographed on silica gel using a mixture of hexane and ethyl acetate (4:1) as eluent to afford the crude β-keto ester (3.62 g). To sodium hydride (1.50 g, 37.5 mmol as 60% assay) in a mixed solvent (benzene:DMF = 2:1; 30 mL) was added a solution of the β-keto ester (3.62 g) in the same solvent (30 mL). After 30 min of stirring, methyl iodide (2.35 mL, 37.7 mmol) was added, and the mixture was allowed to stand for 2 h at ambient temperature. Saturated ammonium chloride solution was added to the mixture, and an organic layer was extracted with ether. After the solvent was removed, the residue was subjected to chromatography on silica gel (hexane:ethyl acetate = 9:1) to give methyl 3-(2-methylphenyl)-2,2-dimethyl-3-oxopropanoate (**4a**) (2.27 g, 64%). For **4a**: ^{1}H NMR(400 MHz) δ 1.50(s, 6H), 2.35(s, 3H), 3.63(s, 3H), 7.15−7.19(m, 1H), 7.23−7.26(m, 2H), 7.28−7.32(m, 1H); ^{13}C NMR(100 MHz) δ 20.5(q), 23.6(q), 52.3(q), 55.6(s), 125.1(d), 125.5(d), 130.1(d), 131.5(d), 136.8(s), 137.9(s), 174.5(s), 204.0(s); IR(cm^{-1}) 1734(C=O), 1692(C=O). Anal. Calcd for $C_{13}H_{16}O_3$: C, 70.89; H, 7.32. Found: C, 70.5; H, 7.4.

Compounds **4b**−**d** were prepared from *o*-tolualdehyde and ethyl 2-bromo-2-methylpropanoate (**2b**), isopropyl 2-bromopropanoate (**2c**), and *tert*-butyl 2-bromopropanoate (**2d**), respectively, by the similar procedures as above. The isopropyl ester **2c** was prepared from 2-bromopropanoic acid and 2-propanol in the presence of concentrated sulfuric acid and *tert*-butyl ester **2d** was prepared from 2-bromopropanoyl bromide and *tert*-butyl alcohol in the presence of *N*,*N*-dimethylaniline.[16]

Preparations of β-Oxo Esters 4e,f. To a suspension of sodium hydride (824 mg, 22.3 mmol as 65% assay) in THF (15 mL) was added a THF (5 mL) solution of 2,4-diethylacetophenone (**5a**) (3.89 g, 22.1 mmol). After several hours of stirring at room temperature, dimethyl carbonate (**6**) (2.5 mL, 28.9 mmol) was added, and the mixture was heated under reflux for 1.5 h. Saturated ammonium chloride solution was added to the mixture, and an organic layer was extracted with ether. After the solvent was removed, the residue was purified by chromatography on silica gel (hexane:ethyl acetate = 10:1) to afford the corresponding β-keto ester (3.832 g). This ester was methylated with methyl iodide to give methyl 3-(2,4-diethylphenyl)-2,2-dimethyl-3-oxopropanoate (**4e**) (2.32 g, 40%) by the same procedure as that for the preparation of **4a**. For **4e**: ^{1}H NMR(400 MHz) δ 1.20−1.25(m, 6H), 1.50(s, 6H), 2.61−2.70(m, 4H), 3.63(s, 3H), 6.99(d, J = 8 Hz, 1H), 7.10(s, 1H), 7.19(d, J = 8 Hz, 1H); ^{13}C NMR(100 MHz) δ 15.1(q), 16.0(q), 23.9(q), 26.9(t), 28.7(t), 52.3(q), 55.4(s), 124.5(d), 126.0(d), 129.8(d), 134.7(s), 143.7(s), 146.8(s), 174.8(s), 203.6(s); IR(cm^{-1}) 1742(C=O), 1694(C=O). Anal. Calcd for $C_{16}H_{22}O_3$: C, 73.25; H, 8.45. Found: C, 73.1; H, 8.5.

Compound **4f** was prepared from 2,4-diisopropylacetophenone (**5b**) and dimethyl carbonate as the same procedure as above.

Preparation of β-Oxo Amide 4g. A mixture of methyl *o*-toluoyl acetate (966 mg, 5.03 mmol) and diethylamine (1 mL, 9.67 mmol) was heated at 150 °C for 14 h. The resulting viscous oil was subjected to chromatography on silica gel (hexane:ethyl acetate = 5:1) to give **7** (891 mg, 76%). The amide **7** was methylated with methyl iodide by the same procedure as that for the preparation of **4a**. Chromatography of the crude mixture on silica gel (hexane:ethyl acetate = 3:1) gave *N*,*N*-diethyl-3-(2-methylphenyl)-2,2-dimethyl-3-oxopropanamide (**4g**) (80 mg, 8%). For **4g**: mp 43 °C (hexane); ^{1}H

(16) Vollmar, A.; Dunn, M. S. *J. Org. Chem*. **1960**, *25*, 387.

Table 2. Methods for Irradiation of β-Oxo Esters 4a−f and Amides 4g−i

β-oxo esters or amides	solvent	mg/mL	irradiation period	method	convn (%)	solvent used for WCC (hexane:AcOEt)	product yields (%)
4a	MeOH	602/120	3 h[a]	A	97	6:1	**9a** (23%), **10a** (9%)
4b	MeOH	608/120	3 h[a]	A	92	4:1	**9a** (27%), **10b** (11%)
4c	MeOH	605/120	5 h[a]	A	95	4:1	**9a** (15%), **10c** (35%)
4d	MeOH	604/120	5 h[a]	A	93	6:1	**9a** (3%), **10d** (69%)
4e	MeOH	261/30	3 h[a]	A	100	10:1	**9e** (25%), **10e** (32%)
4f	MeOH	177/2	17 d[b]	D	100		**10f** (100%)
4g	MeOH	80/2	10 d[b]	D	100	5:1	**10g** (63%)
4h	MeOH	101/1.5	10 d[b]	D	100	1:3	**10h** (75%)
4i	MeOH	153/140	3 d[a]	A	100	1:3	complex mixture
4a	hexane	181/1.5	4 d[b]	D	94	6:1	**10a** (70%)
4e	hexane	413/25	19.5 h[a]	A	100	8:1	**10e** (82%)
4f	hexane	1189/350	8 d[b]	A	58	8:1	**10f** (73%)
4a	hexane	596/120	6 h[a]	C	94	6:1	**10a** (67%), **14** (6%)
4e	hexane	190/30	13 h[a]	B	100	6:1	**13** (38%)
4f	hexane	1306/350	12 d[b]	B	52	8:1	**10f** (42%), **11a** (40%)
4f	MeOH	1039/350	5 d[b]	B	100	8:1	**10f** (73%), **11a** (5%)
4g	MeOH	195/80	20 h[a]	C	63	2:1	**10g** (21%), **15** (46%)

[a] A 100 W high-pressure mercury lamp was used. [b] A 450 W high-pressure mercury lamp was used.

NMR(200 MHz) δ 0.85(br t, J = 7 Hz, 3H), 0.97(br t, J = 7 Hz, 3H), 1.52(s, 6H), 2.50(s, 3H), 2.95(br q, J = 7 Hz, 2H), 3.31(br q, J = 7 Hz, 2H), 7.17−7.35(m, 3H), 7.67(br d, J = 6 Hz, 1H); ^{13}C NMR(50 MHz) δ 11.7(q), 13.2(q), 21.9(q), 25.6(q). 40.0(t), 41.3(t), 55.4(s), 125.3(d), 128.8(d), 131.5(d), 132.3(d), 135.4(s), 139.6(s), 172.6(s), 203.5(s); IR(cm^{-1}) 1683(C═O), 1635(Et_2NC═O). Anal. Calcd for $C_{16}H_{23}NO_2$: C, 73.53; H, 8.86; N, 5.36. Found: C, 73.6; H, 9.0; N, 5.4.

Preparations of β-Oxo Amides 4h,i. To a THF (20 mL) solution of lithium diisopropylamide which was prepared from diisopropylamine (0.8 mL, 5.69 mmol) and butyllithium (1.66 M in hexane; 3.90 mL) was added isobutylnitrile (0.52 mL, 5.72 mmol) at −70 °C. The mixture was warmed to −10 °C and treated with *o*-tolualdehyde (**1**) (0.65 mL, 5.62 mmol). After usual workup, the mixture was subjected to chromatography on silica gel (hexane:ethyl acetate = 2:1) to afford **8a** (788 mg, 74%). To an acetone (5 mL) solution of **8a** (100 mg, 0,53 mmol) was added 0.2 mL of 2.67 M Jones reagent. After usual workup, the mixture was chromatographed on silica gel (hexane:ethyl acetate = 10:1) to afford the corresponding β-keto nitrile (82 mg, 83%). A suspension of the β-keto nitrile (646 mg, 3.43 mmol) in water (1 mL) was heated at 85 °C for 19 h in the presence of 5 mL of concentrated sulfuric acid. The mixture was poured into ice water, and an organic layer was extracted with ether. After the solvent was removed, the residual solid was recrystallized (hexane + ethyl acetate) to give 3-(2-methylphenyl)-2,2-dimethyl-3-oxopropanamide (**4h**) (440 mg, 66%). For **4h**: mp 86 °C (hexane + ethyl acetate); ^{1}H NMR (400 MHz) δ 1.45(s, 6H), 2.31(s, 3H), 6.15(br s, 2H), 7.17(t, J = 7 Hz, 1H), 7.23(d, J = 7 Hz, 1H), 7.28−7.34(m, 2H); ^{13}C NMR(100 MHz) δ 20.1(q), 24.0(q), 55.7(s), 125.2(d), 125.8(d), 130.1(d), 131.3(d), 135.8(s), 138.2(s), 174.7(s), 208.1-(s); IR(cm^{-1}) 3480(NH), 1700(C═O), 1684(NH_2C═O). Anal. Calcd for $C_{12}H_{15}NO_2$: C, 70.22; H, 7.37; N, 6.82. Found: C, 70.2; H, 7.4; N, 6.8.

Compound **4i** was prepared from isobutylnitrile and benzaldehyde by the same procedure as above.

General Procedures for Photolysis of β-Oxo Esters 4a−f and β-Oxo Amides 4 g−i. Irradiations were carried out by four different methods. Method A: A solution of **4** was placed in a glass vessel into which was placed a Pyrex water jacket to cool a lamp inserted in it and irradiated under argon. Method B: A solution of **4** was placed in a glass vessel in the same manner as method A and irradiated under bubbling air. Method C: A solution of **4** was placed in a glass vessel in the same manner as method A and irradiated without bubbling any gas. Method D: A solution of **4** was placed in a Pyrex tube and degassed by freeze−pump−thaw cycles, and the tube was sealed. The tube was placed on the wall of the Pyrex water jacket into which was placed a lamp. After irradiation, the solvent was removed and the residue was chromatographed on silica gel. The irradiation conditions and the solvent used for chromatography are shown in Table 2.

2,2-Dimethyl-3-oxo-3,4-dihydronaphthalen-1(2*H*)-one (9a): mp 60−61 °C (hexane); ^{1}H NMR(400 MHz) δ 1.43-(s, 6H), 3.98(s, 2H), 7.31(d, J = 8 Hz, 1H), 7.41−7.44(m, 1H), 7.57−7.60(m, 1H), 8.09(d, J = 8 Hz, 1H); ^{13}C NMR(100 MHz) δ 21.4(q), 41.4(t), 59.4(s), 127.5(d), 128.1(d), 128.4(d), 130.2-(s), 134.2(d), 136.2 (s), 198.9 (s), 206.7(s); IR(cm^{-1}) 1730-(C═O), 1690(C═O). Anal. Calcd for $C_{12}H_{12}O_2$: C, 76.58; H, 6.42. Found: C, 76.4; H, 6.3.

6-Ethyl-2,2,4-trimethyl-3-oxo-3,4-dihydronaphthalen-1(2*H*)-one (9e): ^{1}H NMR(400 MHz) δ 1.28(t, J = 8 Hz, 3H), 1.40(s, 3H), 1.44(s, 3H), 1.59(d, J = 7 Hz, 3H), 2.74(q, J = 8 Hz, 2H), 4.03(q, J = 7 Hz, 1H), 7.21−7.24(m, 2H), 7.98(d, J = 8 Hz, 1H); ^{13}C NMR(100 MHz) δ 14.9(q), 15.4(q), 19.6(q), 24.9(q), 29.1(t), 43.4(d), 58.2(s), 126.0(d), 127.1(d), 128.1(s), 128.1(d), 141.5(s), 151.6(s), 199.4(s), 209.6(s); IR(cm^{-1}) 1732(C═O), 1684(C═O). A satisfactory chemical analysis of **9e** was not obtained because of its instability. It decomposes to yellow viscous oil.

Methyl 2-(1′-Hydroxy-1′,2′-dihydrobenzocyclobuten-1′-yl)-2-methylpropanoate (10a): bp 91−94 °C(0.4 mmHg); ^{1}H NMR(400 MHz) δ 1.22(s, 3H), 1.26(s, 3H), 3.09(d, J = 14 Hz, 1H), 3.50(d, J = 14 Hz, 1H), 3.70(br s, 1 H), 3.77(s, 3H), 7.1−7.3(m, 4H); ^{13}C NMR(100 MHz) δ 20.9(q), 21.4(q), 42.4(t), 47.7-(s), 51.8(q), 84.1(s), 121.9(d), 123.1(d), 126.9(d), 129.1(d), 142.0(s), 147.0(s), 177.7 (s); IR(cm^{-1}) 3500(OH), 1720(C═O). Anal. Calcd for $C_{13}H_{16}O_3$: C, 70.89; H, 7.32. Found: C, 70.8; H, 7.3.

Methyl 2-(4′-Ethyl-1′-hydroxy-1′,2′-dihydro-2′-methylbenzocyclobuten-1′-yl)-2-methylpropanoate (10e): ^{1}H NMR(400 MHz) δ 1.09(s, 3H), 1.22(t, J = 8 Hz, 3H), 1.37(d, J = 8 Hz, 3H), 1.46(s, 3H), 2.63(q, J = 8 Hz, 2H), 3.64(q, J = 8 Hz, 1H), 3.79(s, 3H), 4.25(s, 1H), 6.98(s, 1H), 7.04(d, J = 8 Hz, 1H), 7.12(d, J = 8 Hz, 1H); ^{13}C NMR(100 MHz) δ 14.6(q), 15.9(q), 22.3(q), 24.7(q), 29.6(t), 46.9(s), 52.0(q), 54.0(d), 85.6-(s), 121.1(d), 121.5(d), 127.0(d), 142.0(s), 145.9(s), 146.9(s), 179.0(s); IR(cm^{-1}) 3504(OH), 1714(C═O). Anal. Calcd for $C_{16}H_{22}O_3$: C, 73.25; H, 8.45. Found: C, 72.7; H, 8.5.

Methyl 2-(1′-Hydroxy-4′-isopropyl-1′,2′-dihydro-2′,2′-dimethylbenzocyclobuten-1′-yl)-2-methylpropanoate (10f): ^{1}H NMR(400 MHz) δ 1.09(s, 3H), 1.23(d, J = 7 Hz, 6H), 1.36(s, 6H), 1.53(s, 3H), 2.87(sept, J = 7 Hz, 1H), 3.75(s, 3H), 3.79(s, 1H), 6.95(s, 1H), 7.06(d, J = 7 Hz, 1H), 7.16(d, J = 7 Hz, 1H); ^{13}C NMR(100 MHz) δ 23.0(q), 23.3(q), 24.1(q), 24.2-(q), 25.9(q), 26.9(q), 34.8(d), 47.6(s), 51.9(q), 54.0(s), 87.0(s), 117.8(d), 122.0(d), 125.8(d), 141.3(s), 150.5(s), 152.4(s), 179.2-(s); IR(cm^{-1}) 3516(OH), 1712(C═O). Anal. Calcd for $C_{18}H_{26}O_3$: C, 74.45; H, 9.02. Found: C, 74.4; H, 9.1.

***N,N*-Diethyl2-(1′-Hydroxy-1′,2′-dihydrobenzocyclobuten-1′-yl)-2-methylpropanamide (10 g).** ^{1}H NMR(400 MHz) δ

1.19(br t, J = 7 Hz, 6H), 1.31(s, 3H), 1.34(s, 3H), 3.15(d, J = 14 Hz, 1H), 3.40(d, J = 14 Hz, 1H), 3.35−3.52(m, 4H), 5.35(s, 1H), 7.11(d, J = 7 Hz, 1H), 7.18−7.24(m, 3H); ^{13}C NMR(100 MHz) δ 13.3(q), 20.8(q), 21.4(q), 41.8(t), 42.4(t), 47.1(s), 86.8(s), 122.5(d), 123.1(d), 127.0(d), 128.9(d), 142.7(s), 148.1(s), 177.2(s); IR(cm^{-1}) 3450(OH), 1611(C=O). Anal. Calcd for $C_{16}H_{23}NO_2$: C, 73.53; H, 8.87; N, 5.36. Found: C, 72.8; H, 9.0; N, 5.1.

Methyl 2-(1′-Hydroxy-6′-isopropyl-4′,4′-dimethyl-1′,4′-dihydrobenzo[*d*][1,2]dioxin-1′-yl)-2-methylpropanoate (11a): ^{1}H NMR(400 MHz) δ 1.08(s, 3H), 1.25(d, J = 7 Hz, 6H), 1.48(s, 3H), 1.56(s, 3H), 1.65(s, 3H), 2.90(sept, J = 7 Hz, 1H), 3.78(s, 3H), 5.64(s, 1H), 7.00(d, J = 2 Hz, 1H), 7.12(dd, J = 2 and 8 Hz, 1H), 7.43(d, J = 8 Hz, 1H); ^{13}C NMR(100 MHz) δ 21.6(q), 23.8(q), 23.8(q), 23.8(q), 26.4(q), 26.6(q), 33.9(d), 50.5(s), 52.6(q), 80.6(s), 103.2(s), 121.9(d), 124.3(d), 125.8(d), 129.0(s), 142.1(s), 149.0(s), 177.1(s); IR(cm^{-1}) 3648(OH), 1710(C=O). A satisfactory elemental analysis of **11a** could not be achieved because of its instability.

Methyl 3-(2-Acetyl-4-ethylphenyl)-2,2-dimethyl-3-oxopropanoate (13): ^{1}H NMR(400 MHz) δ 1.28(t, J = 8 Hz, 3H), 1.54(s, 6H), 2.53(s, 3H), 2.72(q, J = 8 Hz, 2H), 3.68(s, 3H), 7.29−7.36(m, 2H), 7.48(s, 1H); ^{13}C NMR(100 MHz) δ 15.1(q), 23.5(q), 27.8(q), 28.6(t), 52.4(q), 55.1(s), 126.8(d), 128.2(d), 130.8(d), 136.8(s), 138.9(s), 146.6(s), 174.5(s), 200.4(s), 203.9(s). Anal. Calcd for $C_{16}H_{20}O_4$: C, 69.55; H, 7.30. Found: C, 69.7; H, 7.4.

Methyl 2-Methyl-2-phthalidylpropanoate (14): bp 97−100 °C (0.4 mmHg); ^{1}H NMR(400 MHz) δ 1.01 (s, 3H), 1.36 (s, 3H), 3.81(s, 3H), 5.80(s, 1H), 7.35(d, J = 8 Hz, 1H), 7.55(t, J = 8 Hz, 1H), 7.65(t, J = 8 Hz, 1H), 7.91 (d, J = 8 Hz, 1H); ^{13}C NMR(100 MHz) δ 18.4(q), 22.6(q), 46.7(s), 52.3(q), 84.3(d), 122.8(d), 125.8(d), 126.9(s), 129.4(d), 134.0(d), 147.0(s), 170.1(s), 175.3(s); IR(cm^{-1}) 1780(C=O), 1730(C=O). Anal. Calcd for $C_{13}H_{14}O_4$: C, 66.66; H, 6.02. Found: C, 66.5; H, 6.1.

***N,N*-Diethyl 2-Methyl-2-phthalidylpropamide (15):** mp 106 °C (hexane + benzene); ^{1}H NMR(400 MHz) δ 0.84(s, 3H), 1.19(br t, J = 8 Hz, 6H), 1.58(s, 3H), 3.34−3.41(m, 2H), 3.54(br s, 2H), 6.10(s, 1H), 7.48−7.52(m, 1H), 7.60−7.62(m, 2H), 7.87(d, J = 8 Hz, 1H); ^{13}C NMR(100 MHz) δ 13.3(q), 18.0(q), 23.7(q), 41.7(t), 46.5(s), 86.0(d), 125.0(d), 125.0(d), 127.2(s), 128.9(d), 133.9(d), 148.3(s), 170.7(s), 173.9(s); IR(cm^{-1}) 1772(C=O), 1621(C=O). Anal. Calcd for $C_{16}H_{21}NO_3$: C, 69.79; H, 7.69; N, 5.09. Found: C, 69.9; H, 7.7; N, 5.1.

Irradiation of 3-Phenyl-2,2-dimethyl-3-oxopropanamide (4i) in Methanol. A methanol solution (140 mL) of 3-phenyl-2,2-dimethyl-3-oxopropanamide (**4i**) (153 mg, 0.80 mmol) was irradiated for 3 days. From the irradiation mixture, no identifiable products were isolated by chromatography.

Acknowledgment. This work was partially supported by a Grant-in Aid for Scientific Research (C) No. 08640668 (M. Y.) from the Ministry of Education, Science, Sports and Culture, Japan.

Supporting Information Available: Physical properties of compounds **4b**−**d**, **f**, **i** and **10b**−**d**, **h**, and ^{1}H and ^{13}C NMR spectra for compounds **9e** and **11a** (7 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

JO981433B