Synthetic Photochemistry. LXII.[1)]
The Photoaddition of 4-Methyl-2-oxo-γ-valerolactone to Cycloalkenes

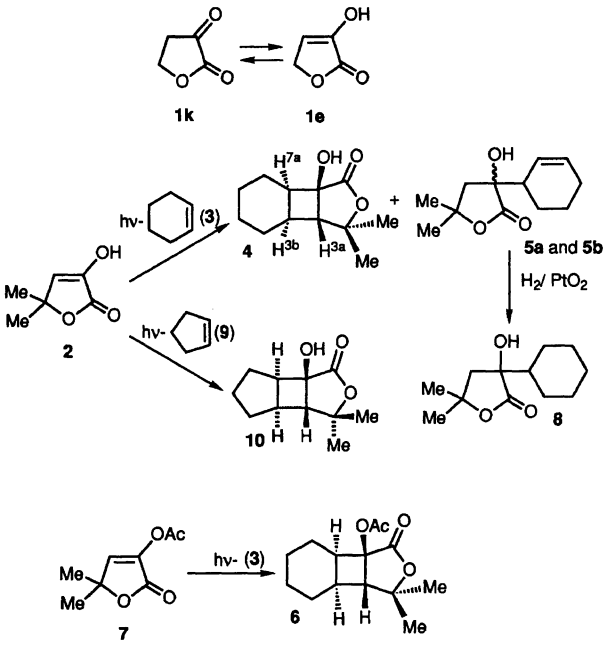
Toshihide HATSUI,* Toshio KITASHIMA,† and Hitoshi TAKESHITA*
Institute of Advanced Material Study, 86, Kyushu University, Kasuga-koen, Kasuga, Fukuoka 816
†Graduate School of Engineering Sciences, 39, Kyushu University, Kasuga-koen, Kasuga, Fukuoka 816
(Received July 14, 1993)

Synopsis. Photocycloaddition of 4-methyl-2-oxo-γ-valerolactone to cycloalkenes gave [2+2] cycloadducts, together with the ene reaction products. The stereostructures of photoproducts were identified by detailed NMR spectral analyses including NOE experiments. The photocycloadducts were convertible to (2-alkenylcycloalkyl)glyoxalic acids.

The photoaddition reaction of enolized β-dicarbonyl compounds with alkenes has wide applications in organic syntheses.[2,3)] As a modified β-dicarbonyl functions, several cyclic enol derivatives of acetoacetic acid were also reported.[4,5)]

The 2-oxo-γ-butyrolactone (**1**: α-tetronic acid) is known to exist in the enol form (**1e**, a cyclic α,β-unsaturated carbonyl system), rather than the keto form (**1k**), and therefore, its [2+2] cycloadducts should have a hydroxyl group on the cyclobutane ring, which may be crucial in the subsequent transformations of the strained cyclobutane moiety. Herein described are results of the photoreactions of a dimethyl derivative of **1**, 4-methyl-2-oxo-γ-valerolactone (**2**), with typical cycloalkenes.

The UV-light irradiation of 4-methyl-2-oxo-γ-valerolactone (**2**) with cyclohexene (**3**) afforded two products (**4** and **5**), in 62 and 7% yields, respectively, which were separated via chromatography (Scheme 1). The major product, **4**, was identified as a 1:1-adduct from mass spectral measurement of the molecular weight (M^+ = 210). Its IR spectrum showed it to be a lactone; the $\nu_{C=O}$ at 1745 cm^{-1} is in longer wavelength region than that of typical absorption maxima for γ-lactones, but it should be reasonable as **4** has an α-hydroxyl group. Indeed, the similar photocycloadduct (**6**) obtained from the acetate of **2** (3-acetoxy-5,5-dimethyl-2-furanone, **7**) and **3** had two $\nu_{C=O}$ maxima at 1785 and 1750 cm^{-1}. The ^1H NMR spectrum of **4** showed two methyl singlets, at δ=1.34 and δ=1.45, and three methine proton signals, ascribable to H-3a (δ=2.66), H-3b (σ=2.00), and H-7a (δ=2.41), respectively. Although assignment of the signals is unambiguous from the observed coupling sequence, stereochemistry of the ring juncture could not be deduced from the magnitudes of coupling constants between these methine protons, which were both 8 Hz. Therefore, NOE experiments were done; when the methyl proton signal at δ=1.34 was irradiated, the intensities of three methine proton signals were all increased. This methyl group, therefore, should be cis

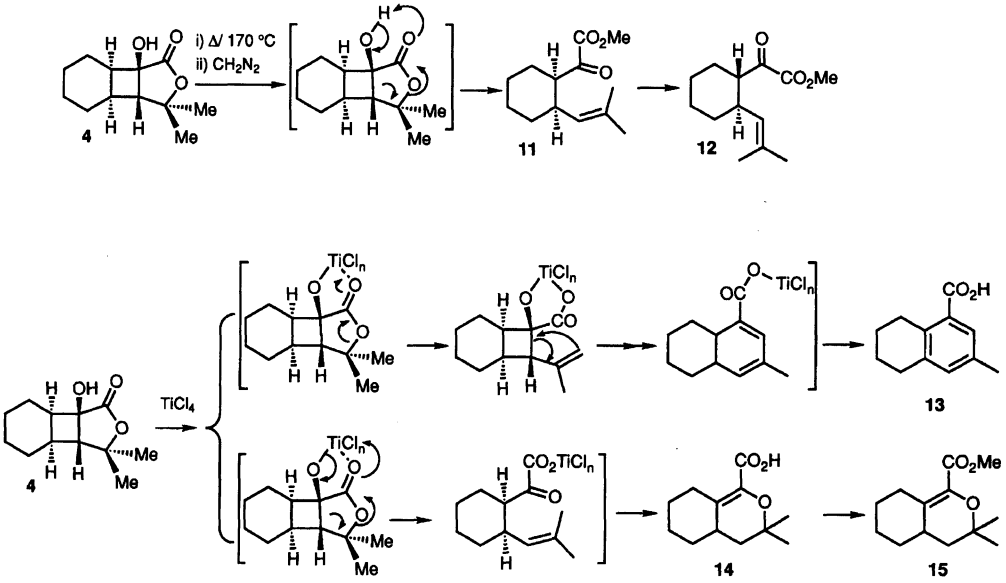


Scheme 1.

to the H-3b and H-7a on the cyclobutane ring. Thus, **4** is the *cis-transoid-cis*-adduct of **2** and **3**, [3aα,3bβ,7aβ,7bα]-7b-hydroxy-3a,3b,4,5,6,7,7a,7b-octahydro-3,3-dimethylbenzo[3,4]cyclobuta[1,2-*c*]furan-1(3*H*)-one(2-hydroxy-5,5-dimethyl-4-oxatricyclo[5.4.0^{2,6}]undecan-3-one).

The minor product, **5**, showed the α-hydroxy-γ-lactone function in the IR spectrum. Its ^1H NMR spectrum, however, showed the two olefinic protons at about δ=5.93, suggesting it to be an ene-product. In addition, the ^{13}C NMR spectrum disclosed two isomers, **5a** and **5b**, in a 2:1-ratio, which gave the same dihydro derivative (**8**). The ^1H NMR spectrum of **8** showed signals ascribable to an isolated methylene group (δ=2.04 and 2.11, J=14 Hz). Thus the structure of **8** was identified as 2-cyclohexyl-2-hydroxy-4,4-dimethyl-γ-butyrolactone, and the **5a** and **5b** as the corresponding 2-(2-cyclohexenyl) derivatives.

Next, the reaction of **2** with cyclopentene (**9**) was similarly examined to obtain a single adduct (**10**). Certainly, **10** was a [2+2]cycloadduct from its IR and ^1H and ^{13}C NMR spectra; the coupling constant between H-3b at δ=2.47 and H-6a at δ=2.71 (J=8.1 Hz) indicated it to be the cis configuration. And the NOE between H-3b and the methyl protons at δ=1.44



Scheme 2.

proved their cis-relationship to deduce the *cis-transoid-cis*-structure, i. e., [3aα,3bβ,6aβ,6bα]-3,3a,3b,4,5,6,6a,6b-oxtahydro-6b-hydroxy-3,3-dimethyl-1*H*-cyclopenta-[3,4]cyclobuta[1,2-*c*]furan-1-one (2-hydroxy-5,5-dimethyl-4-oxatricyclo[5.3.0^{2,6}]decan-3-one).

The photocycloadducts have strained four-membered rings with a highly reactive α-hydroxy-γ-lactone moiety, and its behavior under thermolytic conditions should be of interest; since the adducts have the 1,3-dioxygeneted function, which will possibly cause a *retro*-Prins type fragmentation reaction to form olefins and carbonyls.

Thus the adduct **4** was heated at 170 °C for 4 h, and the ester **11** was obtained after methylation with diazomethane (Scheme 2). From the spectroscopic analysis, **11** was assigned to methyl α-oxo-2-(2-methyl-1-propenyl)cyclohexaneacetate. Its stereochemistry was identified as cis by the coupling patterns of methine protons, that is, **11** had axial H-1 proton and equatorial H-2 proton. When **4** was heated for a longer time, the more stable *trans*-isomer **12** was obtained instead.

The results indicates that the proton transfer from the tertiary hydroxyl to the lactone carbonyl is the driving force of the ring cleavage. Then, since a Lewis acid is expected to coordinate with both hydroxyl and carbonyl oxygens, it seems to be worthy examining the lewis-acid catalyzed reaction of **4**. Thus, **4** was treated with titanium(IV) chloride, and the product identified were a tetralin derivative (**13**) and a dihydropyran (**14**) formed in 30 and 16% yield. The ^{1}H and ^{13}C NMR spectra of **13** were consistent with the depicted formula. On the other hand, **14** gave a methyl ester (**15**), and both **14** and **15** showed signals ascribable to the *gem*-dimethyl groups at about 1.17 and 1.35, respectively, but no olefinic proton signal. Therefore, their structures can be also deduced as depicted. Formation of **13** may be explained in terms of a chelation of titanium ion to the α-hydroxy-γ-lactone moiety to cause a dehydration followed by cleavage of the cyclobutane ring to give a cyclohexadiene intermediate, followed by aromatization.

Unlike the cases for disubstituted olefins, the reaction of **2** with 1-methylcyclohexene, a trisubstituted olefin, gave a complex mixture, and no adducts were isolated.

Upon thermolysis, the adducts gave not the *retro*-benzilic acid rearrangement product, but ring-cleavage products. Consequently, the photoaddition reaction of **2** is useful to introduce an alkenyl and an oxalyl group to unactivated olefins, being similar to that of methyl 2,4-dioxopentanoate.

Experimental

Elemental analyses were done by Mrs. M. Miyazawa, of this Institute, Kyushu University. The ^{1}H- and ^{13}C NMR spectra were measured with a GSX-270H Spectrometer, JEOL, in $CDCl_3$. The infrared spectra were measured with an A102 Spectrophotometer, JASCO, and mass spectra were with a JMS-0ISG-2 Spectrometer, JEOL.

Photoreaction of 2 with 3. The mixture of **2**[6] (355 mg), **3** (3.4 g), and EtOAc (2 cm^3) was internally irradiated for 10 h by means of a 400-W high-pressure Hg lamp through a Pyrex-glass filter. After evaporation of the volatile materials in vacuo, the residue thus obtained was chromatographed on silica gel to obtain **4** [colorless needles, mp 155—156 °C, 360 mg, 62%. ^{1}H NMR δ=1.34 (3H, s), 1.45 (3H, s), 1.12 (m), 1.28 (m), 1.50—1.85 (6H, m), 2.00 (1H, tt, J=8, 4 Hz), 2.41 (1H, br. q, J=8 Hz), 2.66 (1H, d, J=8 Hz), and 3.39 (1H, s, OH). ^{13}C NMR δ=21.6, 21.7 (2C), 23.0, 24.9, 25.4, 24.9, 25.4, 28.1, 36.8, 52.9, 76.9, 85.9, and 180.0. IR ν 3450, 2920, 1745, 1250, 1185, 1110, 1065, 990, 950, 905, and 860 cm^{-1}. MS m/z 210 (M$^+$, 5) and 83 (100). Found: C, 68.70; H, 8.60%. Calcd for $C_{12}H_{18}O_3$: C, 68.55; H, 8.63%] and **5** [a colorless oil, 41 mg, 7%. ^{1}H NMR δ=1.42 for **5b**; 1.44 for **5b** (3H, s), 1.53 (3H, s), 2.15 (6H, m), 2.55 (1H, m), 2.68 (1H, m), and 5.97 (2H, m). ^{13}C NMR δ=21.4, 24.2, 25.0,

29.0, 29.2, 43.0, 43.1, 80.0, 82.7, 124.5, 131.5, 177.3 for **5a**; δ=21.2, 23.3, 25.1, 29.0 (2C), 42.46, 42.49, 81.1, 82.2, 125.5, 131.3, and 177.9 for **5b**].

Catalytic Reduction of 5a and 5b. The mixture of **5a** and **5b** (107 mg) was hydrogenated in EtOAc using PtO_2 as catalyst. The crude material was purified by silica-gel column chromatography to give **8** [colorless prisms, mp 83—84 °C, 62 mg, 57%. ^{1}H NMR δ=0.92 (1H, qd, J=13, 3 Hz), 1.05—1.35 (3H, m), 1.44 (3H, s), 1.53 (3H, s), 1.65—1.87 (4H, m), 2.01 (1H, d, J=14 Hz), 2.09 (1H, d, J=14 Hz), 3.79 (1H, s, OH). ^{13}C NMR δ=25.9 (2C), 26.4 (2C), 27.9, 29.2, 42.5, 44.6, 81.1, 82.8, and 178.0. IR ν 3460, 2940, 1750, 1455, 1375, 1275, 1150, and 1120 cm^{-1}. Found: C, 67.80; H, 9.62%. Calcd for $C_{12}H_{20}O_3$: C, 67.89; H, 9.50%].

Photoreaction of Acetate 7 with 3. Similarly, an EtOAc solution (2 cm^3) of **7** (281 mg) and **3** (2.99 g) was irradiated for 1.5 h. After silica-gel column chromatography, the mixture gave **6** [colorless needles, mp 82—83 °C, 99 mg, 23%. ^{1}H NMR δ=0.95—1.87 (8H, m), 1.34 (3H, s), 1.53 (3H, s), 2.09 (3H, s), 2.68 (1H, m), 3.15 (1H, ddd, J=12, 7, 5 Hz), and 3.37 (1H, s, OH). ^{13}C NMR δ=20.4, 20.6, 21.6, 21.7, 22.7, 23.9, 28.6, 30.2, 36.6, 51.1, 83.0, 86.2, 169.3, and 173.3. MS m/z (%) 252 (M$^+$, 3) and 192 (100). IR ν 2850, 1785, 1755, 1450, 1375, 1230, 1180, 1080, 1020, and 920 cm^{-1}. Found: m/z, 252.1357 (M$^+$). Calcd for $C_{14}H_{20}O_4$: 252.1360].

Photoreaction of 2 with 9. Similarly, and EtOAc solution (3 cm^3) of **2** (748 mg) and **9** (3.7 g) was irradiated. After silica-gel column chromatography, the mixture gave **10** [colorless needles, mp 82—83 °C, 374 mg, 32%. ^{1}H NMR δ=1.40 (3H, s), 1.44 (3H, s), 1.45—1.95 (5H, m), 2.09 (1H, m), 2.09 (1H, d, J=4.5 Hz), 2.47 (1H, qd, J=5, 2 Hz), 2.71 (1H, td, J=7, 2 Hz), and 3.26 (1H, s, OH); ^{13}C NMR δ=22.4, 25.2, 25.6, 29.5, 32.6, 32.9, 43.8, 54.1, 74.7, 85.9, and 180.4. MS m/z (%) 196 (M$^+$, 12) and 83 (100). Found: C, 67.53; H, 8.13%. Calcd for $C_{11}H_{16}O_3$: C, 67.32; H, 8.21%].

Thermolysis of 4. a) A toluene solution (4 cm^3) of **4** (115 mg) was heated in a sealed tube at 170 °C for up to 20 h. After cooling, the mixture was treated with an ethereal CH_2N_2, and chromatographed on a silica-gel column. The product mixture analyzed at early stage of the reaction contained only **11** [a colorless oil. ^{1}H NMR δ=1.53 (3H, d, J=1.5 Hz), 1.65 (3H, d, J=1.5 Hz), 1.2—1.85 (8H, m), 3.11 (1H, dq, J=10.3, 4.5 Hz), 3.32 (1H, dt, J=10, 4.5 Hz), 3.82 (3H, s), and 5.24 (1H, dsept, J=10.3, 1.5 Hz). ^{13}C NMR δ=17.7, 21.7, 22.6, 24.2, 26.0, 31.5, 34.4, 48.9, 52.6, 122.7, 133.2, 161.9, and 196.3. IR ν 2930, 2850, 1755 (sh), 1730, 1450, 1270, 1235, and 1070 cm^{-1}. MS m/z (%) 224 (M$^+$, 25) and 69 (100). Found: C, 67.80; H, 9.62%. Calcd for $C_{12}H_{20}O_3$: C, 67.89; H, 9.50%]. However, the products isolated after completion of the reaction mainly consisted of the epimerized product, **12** [a colorless oil, 81 mg, 66%. ^{1}H NMR δ=1.56 (3H, d, J=1.3 Hz), 1.60 (3H, d, J=1.3 Hz), 1.1—1.85 (8H, m), 2.43 (1H, tdd, J=11, 10, 3.5 Hz), 3.08 (1H, td, J=11, 3 Hz), 3.82 (3H, s), and 4.87 (1H, dsept, J=10, 1.3 Hz). ^{13}C NMR δ=17.9, 24.9, 25.3, 25.6, 27.9, 32.8, 39.6, 50.8, 52.7, 127.4, 132.5, 162.1, and 198.0. IR ν 2930, 2850, 1755 (sh), 1730, 1450, 1270, 1235, 1180, 1100, 1070, 980, 840, and 735 cm^{-1}] and a small amount of **11**.

$TiCl_4$-Treatment of 4. An anhydrous CH_2Cl_2 solution (5 cm^3) of **4** (70 mg) was treated with $TiCl_4$ (540 mg) at room temperature for 4 h. The mixture was then neutralized with aq $NaHCO_3$, acidified back with dil HCl, and extracted with $CHCl_3$. Organic solvent was evaporated in vacuo, and the residue thus obtained was chromatographed on a silica-gel column to give **13** [a colorless oil, 14 mg, 30%. ^{1}H NMR δ=1.78 (4H, quint, J=4 Hz), 2.32 (3H, s), 2.79 (2H, t, J=4 Hz), 3.09 (2H, t, J=4 Hz), 7.09 (1H, s), and 7.65 (1H, d, J=1 Hz). ^{13}C NMR δ=20.7, 22.5, 23.3, 27.7, 30.3, 128.5, 129.6, 134.5, 134.9, 136.8, 138.4, and 172.8. MS m/z, 190 (M$^+$, 92) and 145 (100). IR ν 3420, 2930, 1680, 1410, 1280, 1230, and 720 cm^{-1}. Found: m/z, 190.0993 (M$^+$). Calcd for $C_{12}H_{14}O_2$: 190.0993 (M)] and **14** [a colorless oil, 11 mg, 16%. ^{1}H NMR δ=1.13 (1H, qd, J=11, 4 Hz), 1.18 (3H, s), 1.32 (1H, qt, J=14, 3 Hz), 1.36 (3H, s), 1.40 (2H, m), 1.76 (2H, m), 1.76 (1H, q, J=7 Hz), 1.85 (1H, dm, J=13 Hz), 1.95 (1H, br d, J=13 Hz), 2.14 (1H, dquint, J=12, 6 Hz), 3.94 (1H, dm, J=14 Hz), and 8.16 (1H, br s). ^{13}C NMR δ=23.5, 25.9, 27.0, 27.6, 29.6, 33.9, 34.4, 42.0, 75.3, 130.4, 133.0, and 164.4. IR ν 3600—3200, 2930, 1680, 1630, 1450, 1370, 1275, 1225, 1130, 900, and 750 cm^{-1}] which was methylated with CH_2N_2 to the methyl ester (**15**) [a colorless oil. ^{1}H NMR δ=1.09 (1H, qd, J=12, 3 Hz), 1.17 (3H, s), 1.26 (1H, dt, J=14, 5 Hz), 1.35 (3H, s), 1.40 (2H, m), 1.72 (1H, q, J=7, 3.5 Hz), 1.80 (2H, m), 1.91 (1H, dm, J=14 Hz), 2.09 (1H, dqd, J=12, 6, 1 Hz), 3.43 (1H, dm, J=14 Hz), and 3.78 (3H, s). ^{13}C NMR δ=23.1, 25.8, 26.9, 27.7, 29.5, 33.3, 34.2, 42.0, 51.8, 73.6, 125.3, 135.6, and 165.0. MS m/z (%) 224 (M$^+$, 54) and 109 (100). IR ν 2930, 1730, 1630, 1440, 1370, 1280, 1200, and 1135 cm^{-1}. Found: m/z 224.1414 (M$^+$). Calcd for $C_{13}H_{20}O_3$: 224.1411 (M)].

References

1) Part LXI: H. Takeshita, Y.-S. Cui, N. Kato, and A. Mori, *Bull. Chem. Soc. Jpn.*, **66**, 2694 (1993).

2) P. de Mayo and H. Takeshita, *Can. J. Chem.*, **41**, 440 (1963); G. Büchi, J. A. Carlson, J. E. Powell, and L. F. Tietze, *J. Am. Chem. Soc.*, **92**, 2165 (1970); H. Takeshita and S. Tanno, *Bull. Chem. Soc. Jpn.*, **46**, 690 (1973).

3) H. Takeshita and N. Kato, *Yuki Gosei Kagaku Kyokai Shi (J. Syn. Org. Chem. Soc.)*, **44**, 1081 (1986); N. Kato, X. Wu, and H. Takeshita, *Yuki Gosei Kagaku Kyokai Shi*, **50**, 563 (1992).

4) S. W. Baldwin, G. F. Martin, Jr., and D. S. Nunn, *J. Org. Chem.*, **50**, 5721 (1985).

5) J. D. Winkler, J. P. Hey, F. J. Hannon, and P. G. Williard, *Heterocycles*, **25**, 55 (1987); H. Takeshita, Y.-S. Cui, N. Kato, A. Mori, and Y. Nagano, *Bull. Chem. Soc. Jpn.*, **65**, 2940 (1992); H. Takeshita, Y.-S. Cui, N. Kato, and A. Mori, *Chem. Express*, **8**, 169 (1993).

6) H. Poisel, *Chem. Ber.*, **111**, 3136 (1978).