Studies on Ketene and Its Derivatives. XCVII.\textsuperscript{1} Photoreactions of Diketene with Maleic Anhydride and Dimethylmaleic Anhydride

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The photoreactions of diketene with maleic anhydride (4) and dimethylmaleic anhydride (6) gave 2-oxo-1-oxaspiro[3.3]heptane-cis-5,6-dicarboxylic anhydride (5a, b) and 5,6-dimethyl-2-oxo-1-oxaspiro[3.3]heptane-cis-5,6-dicarboxylic anhydride (7a, b), respectively.

Treatment of compounds 5 and 7 with hydrogen chloride in ethanol and methanol afforded the corresponding dialkyl 5-alkoxycarbonyl-3-oxoheptanedioate derivatives (8 and 10) and (9 and 11), respectively.

Keywords—photoreaction; [2+2]cycloaddition; diketene; maleic anhydride; dimethylmaleic anhydride; 2-oxo-1-oxaspiro[3.3]heptane-cis-5,6-dicarboxylic anhydrides; 3-oxoheptanedioates

In the preceding paper of this series, we reported the reaction of diketene with olefinic compounds to give spiro-cyclobutan derivatives. For instance, the photolysis of 3,5,5-trimethyl-2-cyclohexenone (1, R=Me) and 3-acetox-5,5-dimethyl-2-cyclohexenone (1, R=OAc) in diketene afforded the spiro-adducts, 8-hydroxy-4,4,6-trimethyl-2-oxa-cis-bicyclo[4.2.0]octan-8-ylacetic acid β-lactone (2, R=Me) and 6-acetox-7-hydroxy-4,4-dimethyl-2-oxa-cis-bicyclo[4.2.0]octan-7-ylacetic acid β-lactone (3, R=OAc), in good yields.\textsuperscript{3,4} The reaction involves [2+2]cycloaddition between the olefinic double bond of cyclohexene and the exo-methylene double bond of diketene, keeping the β-lactone moiety intact. Since little is known concerning such cycloaddition of diketene, our interest has been focused on the reaction of diketene with maleic anhydride. Robson \textit{et al.}\textsuperscript{5} reported that maleic anhydride underwent [2+2]cycloaddition with olefins to give cyclobutane derivatives. On the other hand, the reaction of diketene with maleic anhydride in the presence of azobisisobutyronitrile was reported to give diketene — maleic anhydride copolymer, which can be used as a builder for detergents.\textsuperscript{6} We therefore re-investigated the reaction of diketene with maleic anhydride under irradiation, and the results are reported here.

![Chart 1](image)

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Reaction of Diketene with Maleic Anhydride (4)

Irradiation of a solution of diketene and maleic anhydride (4) in acetonitrile afforded crystalline products of mp 148—149.5° (5a) and mp 166—167° (5b); on the basis of their elemental analyses and spectroscopic data, these were assigned 2-oxo-1-oxaspiro[3.3]heptane-cis-5,6-dicarboxylic anhydride structures. The configuration of the oxetane oxygen (C₄—O) and the ring junction hydrogen (C₃—H) in the product 5a is cis, while that in 5b is trans.

The infrared (IR) spectra of 5a and 5b both showed β-lactone carbonyl [5a: 1840 cm⁻¹ and 5b: 1835 cm⁻¹] and acid anhydride [5a: 1785 cm⁻¹ and 5b: 1780 cm⁻¹] absorptions. The nuclear magnetic resonance (NMR) spectra showed AB quartet methylene signals [5a: 3.69—4.08 ppm and 5b: 3.38—3.83 ppm] due to C₃-methylene protons and multiplet methine signals [5a: 4.15—4.26 ppm and 5b: 4.07—4.17 ppm] due to the C₂-proton.

Alcoholysis of compounds 5a and 5b resulted in ring fission to give the heptanedioate derivatives (8 and 9). That is, compounds 5a and 5b were treated with hydrogen chloride in ethanol to give the same product, diethyl 5-ethoxycarbonyl-3-oxoheptanedioate (8). The ester (9, R' = Me) was also obtained when compounds (5a and 5b) were treated with HCl-methanol. Structure assignment of the esters (8 and 9) was made on the basis of elemental analyses and spectroscopic data detailed in the experimental section.

Reaction of Diketene with Dimethylmaleic Anhydride (6)

Irradiation of a solution of diketene and dimethylmaleic anhydride (6) in acetonitrile or acetone gave 5,6-dimethyl-2-oxo-1-oxaspiro[3.3]heptane-cis-5,6-dicarboxylic anhydride (7a and 7b).

As described in the experimental section, the IR spectra of 7a and 7b showed absorptions due to β-lactone carbonyl and anhydride carbonyl at 1835 and 1780 cm⁻¹. Because of the anisotropic effect of the oxetane oxygen, the difference of chemical shifts between the C₄- and C₃-methyl protons of compound 7a [1.42 ppm and 1.32 ppm; difference, 0.1 ppm] is larger than that in compound 7b [C₃-CH₃, 1.38 ppm and C₄-CH₃, 1.36 ppm; difference, 0.02 ppm]. Furthermore, the C₃-methylene protons of 7a appeared at 3.54—3.99 ppm as an AB quartet, while those of 7b appeared at higher field (3.27—3.95 ppm).

On the basis of these observations, it was inferred that the configuration of the oxetane oxygen (C₄—O) and the ring junction methyl (C₃—CH₃) in compound 7a is cis, and that in 7b is trans.

![Chemical Diagram]

Chart 2
Treatment of the mixture of 7a and 7b with hydrogen chloride in ethanol and methanol gave the esters 10 and 11, respectively. Structural assignments were made on the basis of elemental analyses and spectroscopic data.

Experimental

IR spectra were taken with a Jasco IR-S spectrophotometer. NMR spectra were measured with a Hitachi R-20 instrument and a JEOL JNM-PS-100 instrument using tetramethylsilane as an internal standard. Melting points are uncorrected. The ultraviolet (UV) light source was a Riko UVL-100HA water-cooled high-pressure mercury lamp (Pyrex filter).

Reaction of Diketene with Maleic Anhydride (4)—A solution of maleic anhydride (4) (3.92 g, 0.04 mol) and diketene (33.6 g, 0.40 mol) in acetonitrile (200 ml) was irradiated for 8 hr with ice-cooling. Removal of the solvent and excess diketene gave a semicrystalline residue, which was triturated with ethyl acetate. The resulting crystalline substance was washed with acetone, and purified by recrystallization from ethyl acetate to give compound 5b as needles (0.65 g, 9%) of mp 148—149.5°. Anal. Calcd for C₉H₈O₂ (5a): C, 52.75; H, 3.32. Found: C, 52.85; H, 3.35. IR ν max cm⁻¹: 1840 (δ-lactone), 1785 (acid anhydride). NMR (DMSO-d₆) δ: 7.28—7.93 (1H, m, C₅-H), 3.04—3.53 (2H, m, C₄-C₃-H). 3.69—4.08 (2H, ABq, J = 16 Hz, 2 × C₂-H), 4.15—4.26 (1H, m, C₂-H). Anal. Calcd for C₉H₈O₂ (5b): C, 52.75; H, 3.32. Found: C, 52.83; H, 3.34. IR ν max cm⁻¹: 1835 (β-lactone), 1780 (acid anhydride). NMR (DMSO-d₆) δ: 3.07—3.17 (2H, m, 2 × C₂-H), 3.38—3.83 (2H, ABq, J = 16 Hz, 2 × C₂-H), 3.63—3.86 (1H, m, C₂-H), 4.07—4.17 (1H, m, C₅-H).

Diethyl 5-Ethoxycarbonyl-3-oxoheptanedioate (8)—a) A solution of 5a (55 mg, 0.3 mmol) in abs. ethanol (3 ml) saturated with dry HCl was stirred at room temperature for 3.5 hr. The reaction mixture was concentrated, and the residue was extracted with ether. After washing with 5% NaHCO₃ and water, the ether solution was dried over Na₂SO₄. After removal of the ether, the residual oil was distilled under reduced pressure to give 82 mg (90%) of a colorless oil (8): bp 116—126° (0.05 mmHg). Anal. Calcd for C₁₈H₂₀O₄ (8): C, 55.62; H, 5.34. Found: C, 55.79; H, 5.75. IR ν max cm⁻¹: 1730 (C=O). NMR (CDCl₃) δ: 1.16—1.35 (6H, t, J = 7 Hz, 3 × OCH₂CH₂). 2.48—2.66 (2H, m, 2 × C₂-H), 2.74—2.88 (2H, m, 2 × C₂-H), 3.00—3.25 (1H, m, C₂-H). 3.38 (2H, s, 2 × C₂-H). 3.90—4.24 (6H, q, J = 7 Hz, 3 × OCH₂CH₂). b) Using the same procedure, treatment of 5b (55 mg, 0.3 mmol) with hydrogen chloride in abs. ethanol gave 8 (79 mg, 87%).

Dimethyl 5-Methoxycarbonyl-3-oxoheptanedioate (9)—A mixture of 5a and 5b (110 mg, 0.6 mmol) was added to methanol (6 ml) saturated with dry hydrogen chloride. The reaction mixture was stirred at room temperature for 4 hr. After removal of methanol, the residue was treated as described above to give 140 mg (90%) of a colorless oil (9): bp 109—110° (0.02 mmHg). Anal. Calcd for C₁₈H₂₀O₄ (9): C, 51.77; H, 6.20. Found: C, 50.49; H, 6.24. IR ν max cm⁻¹: 1735 (C=O). NMR (CDCl₃) δ: 2.50—2.70 (2H, m, 2 × C₂-H), 2.75—3.05 (2H, m, 2 × C₂-H), 3.05—3.35 (1H, m, C₂-H). 3.35 (2H, s, 2 × C₂-H). 3.63 (3H, s, OCH₃). 3.70 (3H, s, OCH₃).

Reaction of Diketene with Dimethylmaleic Anhydride (6)—A solution of dimethylmaleic anhydride (6) (2.52 g, 0.02 mol) and diketene (16.8 g, 0.20 mol) in acetonitrile (200 ml) was irradiated for 5 hr with ice-cooling. The solution was concentrated in vacuo, and the resulting residue was crystallized from ether (20 ml) to give 3.5 g (83%) of a crystalline solid [mixture of 7a and 7b]. Recrystallization from ethyl acetate gave compound 7a as prisms of mp 167—168° (dec.). Anal. Calcd for C₁₆H₁₂O₄ (7a): C, 57.14; H, 4.80. Found: C, 56.90; H, 4.90. IR ν max cm⁻¹: 1835 (β-lactone), 1780 (acid anhydride). NMR (DMSO-d₆) δ: 1.32 (3H, s, C₃-CH₃), 1.42 (3H, s, C₄-CH₃), 2.94 (2H, s, 2 × C₂-H). 3.54—3.99 (2H, ABq, J = 17 Hz, 2 × C₂-H). The mother liquor was concentrated, and the residue was purified by recrystallization from benzene to give colorless prisms (7b) of mp 146—148°. Anal. Calcd for C₁₆H₁₂O₄ (7b): C, 57.14; H, 4.80. Found: C, 57.22; H, 4.80. IR ν max cm⁻¹: 1835 (β-lactone), 1780 (acid anhydride). NMR (DMSO-d₆) δ: 1.36 (3H, s, C₃-CH₃), 1.38 (3H, s, C₄-CH₃), 2.66—3.28 (2H, ABq, J = 15 Hz, 2 × C₂-H). 3.27—3.95 (2H, ABq, J = 17 Hz, 2 × C₂-H).

Diethyl 5-Ethoxycarbonyl-5,6-dimethyl-3-oxoheptanedioate (10)—A suspension of the mixture of 7a and 7b (2.1 g, 0.01 mol) in abs. ethanol (30 ml) saturated with hydrogen chloride was stirred at room temperature for 5 hr. The solvent was evaporated off under reduced pressure, and the residue was extracted with ether. The organic layer was washed with 5% NaHCO₃ and water. After drying over Na₂SO₄, the ether layer was evaporated down, and the residual oil was distilled to give 2.38 g (72%) of a colorless oil (10): bp 110—114° (0.02 mmHg). Anal. Calcd for C₁₆H₁₂O₄ (10): C, 58.17; H, 7.93. Found: C, 57.91; H, 7.78. IR ν max cm⁻¹: 1730 (C=O). IR ν max cm⁻¹: 1725 (C=O), 1740 (C=O). NMR (CDCl₃) δ: 1.11—1.38 (9H, m, 3 × OCH₂CH₂). 1.12 (3H, d, J = 7 Hz, C₃-CH₃). 1.27 (3H, s, C₄-CH₃). 2.67—3.30 (2H, ABq, J = 18 Hz, 2 × C₂-H). 2.76 (1H, q, J = 7 Hz, C₅-H). 3.42 (2H, s, 2 × C₂-H). 3.95—4.35 (6H, m, 3 × OCH₂CH₂).

Dimethyl 5-Methoxycarbonyl-5,6-dimethyl-3-oxoheptanedioate (11)—Using the method described for 10, a suspension of the mixture (7a and 7b) (2.1 g, 0.01 mol) in methanol (20 ml) saturated with dry hydrogen
chloride was stirred for 5 hr at room temperature. Treatment as described above afforded 2.1 g (73%) of a colorless oil (11): bp 132—134°C (0.5 mmHg). Anal. Calcd for C₉H₆O₉ (11): C, 54.16; H, 6.99. Found: C, 54.22; H, 6.88. IR νₒ₇₁ cm⁻¹: 1735 (C=O), IR νₒ₃₂ cm⁻¹: 1740 (C=O). NMR (CDCl₃) δ: 1.13 (3H, d, J = 7 Hz, C₆CH₃), 1.29 (3H, s, C₅CH₃), 2.72 (1H, q, J = 7 Hz, C₄-H), 2.58—3.36 (2H, ABq, J = 18 Hz, 2 x C₂-H), 3.45 (2H, s, 2 x C₆H), 3.65 (6H, s, 2 x OCH₃), 3.72 (3H, s, OCH₃).

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Organic Sulfites containing a 1,2-Oxazine Ring

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In the previous paper, we reported syntheses of 2-phenyltetrahydro-2H-1,2-oxazine-3,5-dione derivatives (1) from γ-bromoacetoacetyl bromide and N-phenylhydroxylamines. As a continuation of our studies on these heterocycles, we have investigated the reduction of the C₅-carbonyl group of 1 to give 2-phenyltetrahydro-2H-1,2-oxazine-3-one. In this connection, we have already reported the transformation of 1,2-diphenylhexahydropyridazine-3,5-dione (4) to give 1,2-diphenyl-1,2,3,6-tetrahydropyrazin-3-one (6) via 5-hydroxy-1,2-diphenylhexahydropyrazin-3-one (5). Namely, reduction of the dione (4) with sodium borohydride gave the 5-hydroxy derivative (5), which, on treatment with phosphorus oxychloride was transformed into the pyrazinone (6). Using this procedure, 2-phenyltetrahydro-2H-1,2-oxazine-3,5-dione (1a, R = H) was reduced with sodium borohydride to give 5-hydroxy-2-phenyltetrahydro-2H-1,2-oxazin-3-one (2a). Reaction of 2a with phosphorus oxychloride or phosphorus trichloride in pyridine resulted in recovery of the starting material. However, treatment of 2a with thionyl chloride in the presence of pyridine did not give the dehydrated compound but a mixture of organic sulfites containing a 1,2-oxazine ring, on which we now report.

Compound 2a was allowed to react with a half equivalent of thionyl chloride in the presence of one equivalent of pyridine in carbon tetrachloride under reflux to afford a colorless crystalline product (3a). The product did not have a sharp melting point and thin-layer

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