Synthetic Photochemistry. XXVI. Synthesis and Characterization of 1,4-Dioxaspiro [4.6] undeca-6,9-diene-5,8-dione, A p-Tropoquinone Monoacetal

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Synthetic Photochemistry. XXVI.[1] Synthesis and Characterization of 1,4-Dioxaspiro[4.6]undeca-6,9-diene-5,8-dione, A p-Tropoquinone Monoacetal

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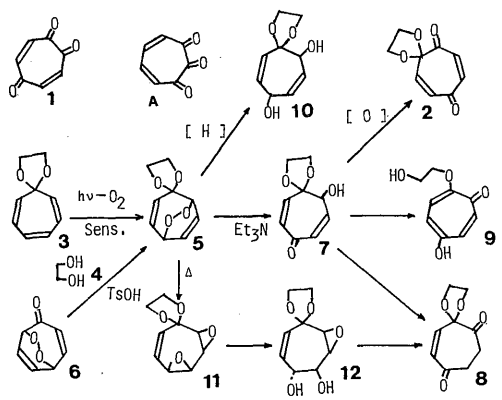
A *p*-Tropoquinone acetal was prepared by the singlet oxygen-oxidation of an ethylene acetal of tropone, and was characterized as two *endo*-Diels-Alder adducts with cyclopentadiene, whose structures were deduced by physicochemical data. Photochemical rearrangement of the acetal yielded a ring-contraction product, 2-hydroxyethyl (2,5-dioxo-3-cyclopentenyl)acetate. The same reaction with *p*-tropoquinone in methanol yielded methyl (2,5-dioxo-3-cyclopentenyl)acetate, along with photoreduced 5-hydroxytropolone.

p-Tropoquinone (**1**)[2] is a unique compound having *o*- and *p*-quinone units within a molecule, and its synthetic studies seem to be started soon after the eventual synthesis of 5-aminohinokitiol[3] and 5-nitrosotropolone,[4] a monooxime of **1**. However, the synthesis of the parent compounds, **1** and *o*-tropoquinone (**A**),[5] has been unsuccessful until 1970's. In this paper, we wish to describe prepara tions of a monoacetal (**2**), an important member of functional derivative of **1**, by two routes, together with its chemical characterization.



[Scheme 1]

Department of Molecular Science and Technology

When an acetone solution of 1,4-dioxaspiro[4.6]undeca-6,8,10-triene (**3**),[6] prepared from tropone and 1,2-ethanediol (**4**), and haematoporphyrin was irradiated by a tungsten lamp under the oxygen atmosphere, a (4+2) π endo-peroxide (**5**) was produced as a sole product. The structure of **5** was followed after the chemical derivation from the tropone endoperoxide (**6**) and **4** with *p*-toluenesulfonic acid (TsOH), together with the NMR spectrum [δ:[7] 4.0 (4H, m), 4.58 (Ha, dddd, J = 7.5, 2.5, 2, 1 Hz), 4.78 (Hb, tm, J=7 Hz), 5.54 (Hc, ddd, J=10.5, 2.5, 1 Hz), 6.24 (Hd, dd, J=10.5, 7 Hz), 6.36 (He, ddd, J=9, 7.5, 1 Hz), and 6.90 (Hf, ddd, J=9, 7, 1 Hz)], revealing an arrangement of Ha-Hc-Hd-Hb-Hf-He for its six methine protons, of which the Ha and Hb are hydrogens on the sp^3-carbons bearing the peroxy group. A mild treatment of **5** with triethylamine afforded a keto alcohol (**7**) in a 98% yield. In its NMR [δ: 4.0 (4H, m), 4.85 (Ha, t, J=2.5 Hz), 6.08 (Hb, dm, J=12.5 Hz), 6.40

(Hc, d, J=12.5 Hz), and 6.51 (Hd, dd, J=12.5, 2.5 Hz)], an occurrence of two low-field signals due to hydrogens, Hc and Hd, at the β-position of α,β-unsaturated keto group was recognized, and from this, the position of the carbonyl group was deduced unambiguously. A prolonged treatment of **7** witht he amine caused further transformation to a diketo acetal (**8**) and 5-hydroxy-2-(2-hydroxyethoxy)tropone (**9**), pale yellow crystals. Low-field signals in the NMR [δ: 3.8-4.1 (4H, m), 6.72 (1H, dm, J=11 Hz), 7.15 (1H, d, J=11 Hz), and 7.27 (2H, br. s)] showed a regeneration of the seven-membered conjugated system in **9**. Treatment of **5** with thiourea yielded a diol (**10**) in an 83% yield. The coupling parameters observed in its MNR [δ: 4.0 (4H, m), 4.45 (Ha, dt, J=4.5, 2 Hz), 4.95 (Hb, m), 5.39 (Hc, dd, J=12.5, 2.7 Hz), 5.56 (Hd, ddd, J=11, 4.5, 2.7 Hz), 5.78 (He, ddd, J=12.5, 2, 1.5 Hz), and 5.87 (Hf, dddd, J = 11, 2.7, 2, 1.5 Hz] indicated partial arrangements, Ha-Hd-Hf and Hc-He, and furthermore, occurrences of the long-range couplings between Ha and He, and He and Hf, assured by double irradiation experiments, clarified the complete arrangement as Ha-Hd-Hf-Hb-Hc-He-X- (Ha), where X denotes a quarternary carbon. Therefore, the structure is deduced as shown.

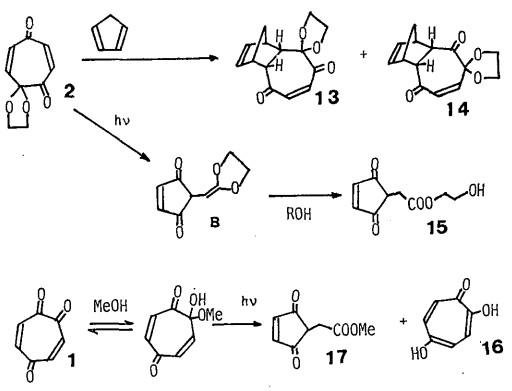
Pyrolysis of **5** also yielded **7**, **8**, and a diepoxide (**11**), which was easily converted to **8** *via* an unstable dihydroxy acetal (**12**). An oxidation of **7** by manganese dioxide or chromium oxide-pyridine complex gave pale yellow crystals, mp 61-62°C. The ^{13}C-NMR spectrum of this showed two carbonyl carbon signals at 189.6 and 191.9 ppm, together with four olefinic carbons, 133.3, 133.8, 137.5, and 139.1, and the acetal carbon, 106.5. Therefore, this is the desired acetal, 1,4-dioxaspiro[4.6]undeca-6, 9-diene-5, 8-dione (**2**). The other spectral data were also in accord with the formulation.

The Diels-Alder reaction of **2** with cyclopentadiene gave two $(4+2)\pi$ adducts, **13** (42%) and **14** (29%). In the IR spectra, **13** showed two carbonyl absorptions due to unsaturated ketone groups [ν: 1695, 1680 cm^{-1}], while **14** showed a saturated and an unsaturated ketone absorptions [ν : 1730, 1675 cm^{-1}]. The endo stereochemistry for both adducts was deduced from the magnitudes of the coupling constants, *i.e.*, in the NMR of **13** [δ: 1.5 (2H, m), 2.92 (Ha, dd, J=10.5, 3 Hz), 3.16 (2H, br. s), 3.46 (Hb, dd, J=10.5, 3 Hz), 3.7-4.1 (4H, m), 5.96 (1H, dd, J=5.5, 3 Hz), 6.14 (1H, dd, J=5.5, 3 Hz), 6.30 (1H, d, J=13 Hz), and 6.54 (1H, d, J=13 Hz)] and **14** [δ: 1.5 (2H, m), 3.3 (2H, m), 3.51 (Ha, dd, J=10.5, 3.5 Hz), 3.72 (Hb, dd, J=10.5, 3 Hz), 3.8-4.2 (4H, m), 6.00 (1H, d, J=12 Hz), 6.18 (1H, d, J=12 Hz), and 6.0-6.3 (2H, m)], the methine protons (Ha and Hb) spin-coupled with the bridge-head protons with J=3 Hz. Furthermore, the chemical shifts for the protons in the enedione and its monoacetal chromophores were in somewhat high field, suggesting a strong anisotropic effect from the double bond in the opposite side of the molecules. It is known that **1** also yields an *endo*-$(4+2)\pi$ adduct.[8]

By means of a high-pressure mercury lamp, the UV-light irradiation of **2** in methanol or in methanol and benzene gave a colorless oil, **15**. The ^{13}C-NMR spectrum of **15** [δ(C): 29.5, 46.8, 60.7, 66.8, 149.1 (2C), 170.7, and 201.8 (2C)] suggested a symmetrical structure, and

the IR spectrum [$\nu_{C=O}$: 1720 cm^{-1}] deduced its skeleton to be the cyclopentenedione. Thus, **15** should be expressed as 2-hydroxyethyl (2, 5-dioxo-3-cyclopentenyl)acetate. Obviously, a ketene acetal (**B**) should be a precursor of **15**. The formation of **15**-d_1, the photoproduct in methanol-d_4 (MeOD), suggested the hydrolysis of **B** during the irradiation.

According to Ito *et al.*,[8] the photoreaction of **1** with styrene in methanol gives a 1, 4-dioxene derivative, the $(4+2)\pi$ cycloadduct and the photoreduction product, 5-hydroxytropolone (**16**), but no other product. However, this easy photocleavage of **2** to **15** suggests that the hemiacetalized **1**[2] must undergo a similar photocleavage in protic solvents. Indeed, an irradiation of **1** by means of a high-pressure mercury lamp in benzene produced no identifiable product, but in methanol it gave **16** and methyl (2, 5-dioxo-3-cyclopentenyl) acetate (**17**). However, the photoreaction of **1** in **4** gave a complex results, and a product isolated from the mixture was not identical with **15**.[10]



[Scheme 2]

Frequently, the cyclopentenediones have been utilized as synthones in various natural products syntheses, and a facile formation of the functionalized cyclopentenediones from troponoids would provide a method in cyclopentanoid natural product syntheses.

Experimental

Preparation of **3**, *the Ethylene Acetal of Tropone.* A CH_2Cl_2 solution (5 cm^3) of tropone (1.33g) and FSO_3Me (1.46g) was allowed to stand at room temperature for 20 h, and then evaporated the solvent to leave brownish residue which was then dissolved in **4** (9 cm^3), and kept at room temperature for several d under the N_2-atmosphere with magnetical stirring. The mixture was then poured into a mixture of aqueous Na_2CO_3 and hexane, and fractionated by hexane and water. The organic layer was dried on $MgSO_4$. The residue obtained by removal of the solvent gave a pale yellow oil, 0.84g (44 %), which was identical with the authentic sample.[6] The aqueous layer yielded the recovered tropone, 670 mg (50 %) by repeated extractions with $CHCl_3$.

Sensitized-photooxidation of **3**. *Formation of* **5**. An acetone solution (11 cm^3) of **3** (445 mg) and haematoporphyrin (13 mg) was irradiated by means of a 500-W tungsten lamp for few d under the O_2-atmosphere. After evaporation of the solvent, the residue was chromatographed on a silica-gel column with hexane-ethyl acetate (9 : 1) to give **5**, colorless crystals, mp 150–152°C (dec) (from benzene), 467 mg (87 %) [Found: C, 59.61; H, 5.54 %. Calcd for $C_9H_{10}O_4$: C, 59.33; H, 5.53 %. δ(C): 64.5, 65.8, 73.8, 79.9, 107.2, 125.2, 130.8, 132.1, and 137.3. ν: 1395, 1180, 1110, 995, 950, 760 cm^{-1}. λ_{max}^{MeOH}: 207 nm (ε=1700)].

Reductive Cleavage of **5** *with Thiourea.* A tetrahydrofuran solution of **5** (373 mg)

was treated with thiourea (156 mg) at room temperature for 24 h. Silica-gel column chromatography of the mixture afforded colorless crystals (**10**), mp 152–154°C (from MeOH), 315 mg (83 %) [Found: C, 58.63; H, 6.56 %. Calcd for $C_9H_{12}O_4$: C, 58.69; H, 6.57 %. δ(C): 66.8, 67.3, 68.7, 73.3, 106.5, 128.9, 130.6, 137.8, and 138.1. ν: 3440, 1620, 1030, 810 cm^{-1}].

Base-induced Isomerization of **5**. *Formation of* **7**. A mixture of benzene (2 cm^3), **5** (14.3 mg) and anhydrous Et_3N (30 mg) was refluxed for 1 h. The mixture was chromatographed on a silica-gel column to give **7**, a colorless oil, 14.3 mg (98 %) [Found: *m/e*, 182.0589 (M^+). Calcd for $C_9H_{10}O_4$: 182.0579. δ(C): 66.0, 66.3, 72.7, 106.7, 128.9, 132.2, 141.8, 144.1. and 190.4. ν: 3450, 1665, 1605 cm^{-1}. λ_{max}^{MeOH}: 226 nm (ε=8700)].

Prolonged Base Treatment of **5**. *a*) A benzene solution (2 cm^3) of **5** (46.7 mg) was heated to reflux with Et_3N (60 mg) for prolonged period. After 3.5 h, the product mixture, fractionated through a silica-gel column, was consisted of **7** (11.8 mg, 25 %) and **8** (a colorless oil, 24.5 mg, 53 %) [Found: *m/e*, 182.0580 (M^+). δ: 2.76 (2 H, m), 3.08 (2 H, m), 4.0 (4H, m), 6.18 (1 H, d, J=12 Hz), and 6.52 (1H, d, J=12 Hz). δ(C): 32.5, 36.2, 65.8 (2C), 105.6, 134.3, 140.5, 199.2, and 200.3].

b) Similarly, a benzene solution (50 cm^3) of **5** (396 mg) was treated with Et_3N (50 mg); after 24 h, the mixture showed a presence of a single compound, **9**, pale yellow crystals, mp 198–200°C, 362.3 mg (92 %) [Found C, 59.10; H, 5.58 %. Calcd for $C_9H_{10}O_4$: C, 59.33; H, 5.53 %. δ(C): 61.4, 72.2, 116.9, 120.9, 134.4, 138.6, 160.6, 163.0, and 178.6. ν: 3420, 1590, 1530, 1470 cm^{-1}. λ_{max}^{MeOH}: 251 nm (ε=14200), 310 (10500), 380 (13000)]. Methyl ether of **9** was prepared by diazomethane in acetone, a colorless crystals, mp 110.5–112.5°C (from benzene) [Found: *m/e*, 196.0751 (M^+). Calcd for $C_{10}H_{12}O_4$: 196.0736. δ: 3.78 (3H, s), 3.9–4.2 (4H, m), 6.36 (1H, dm, J=11 Hz), 6.90 (1 H, d, J=11 Hz), 7.08 (1H, dd, J=12.5, 2 Hz), and 7.24 (1H, dd, J=12.5, 1.5 Hz). δ(C): 55.7, 60.6, 71.6, 108.1, 117.4, 133.3, 137.5, 159.2, 160.2, and 179.8].

Acid-catalyzed Acetalization of **6** *with* **4**. A benzene solution (8 cm^3) of **6** (102 mg), **4** (1.5 cm^3), and TsOH (1.3 mg) was refluxed for 7 h with azeotropic removal of water. The mixture was then washed with aqueous NaCl, and water, and the aqueous layer was extracted with $CHCl_3$. Removal of the solvent gave colorless needles, mp 152–154°C, 96.8 mg (72 %), which was identical with **5**.[11]

Thermolysis of **5**. A xylene solution (8 cm^3) of **5** (310mg) was refluxed for 18 h. Then, silica-gel chromatography of the mixture with hexane-ethyl acetate (9 : 1) yielded **7**, 94.5 mg (35%), and a colorless oil, **11**, 46.9 mg (15 %) [Found: *m/e*, 182.0588 (M^+). Calcd for $C_9H_{10}O_4$: 182.0579. δ: 3.31 (1 H, dd, J=4, 1.5 Hz), 3.4–3.6 (3 H, m), 3.7–4.2 (4H, m), 5.63 (1 H, dd, J=11.5, 1.5 Hz), and 6.00 (1 H, ddd, J=11.5, 2, 1.5 Hz). δ(C): 48.8, 52.8, 53.8, 57.8, 64.8, 65.4, 107.0, 126.6, and 134.3], which was spontaneously hydrolyzed to colorless crystals, mp 100–103°C (from benzene), **12** [Found: C, 53.83; H, 6.05 %. Calcd for $C_9H_{12}O_5$: C, 53.99; H, 6.04 %. ν: 3450, 3400, 1240, 910, 835 cm^{-1}].

MnO_2-Oxidation of **7** *to* **2**. A $CHCl_3$ solution (2 cm^3) of **7** (115 mg) was stirred with MnO_2 for 30 min. The product was chromatographed on a silica-gel column

with hexane-ethyl acetate (9 : 1) to give **2**, pale yellow needles, mp 61.5-62°C (from CCl_4), 78.2 mg (69%) [Found: C, 59.66; H, 4.54%. *m/e*, 180.0414 (M^+). Calcd for $C_9H_8O_4$: C, 60.00; H, 4.48%. *m/e*, 180.0420. δ: 3.9-4.2 (4H, m), 6.26 (1H, dt, J=12, 0.8 Hz), 6.56 (2H, d, J=0.8 Hz), and 6.58 (1H, d, J=12 Hz). ν: 1703, 1660, 1630 cm^{-1}. λ_{max}^{MeOH}: 227.5 nm (ε=9200), 353.5 (160)].

CrO_3-Oxidation of **7**. A CH_2Cl_2 solution (5 cm^3) of **7** (100 mg) was treated with CrO_3-2Py (1.67 g) to give **2**, 47.2 mg (48%).

MnO_2-Oxidation of ***10*** *to* ***2***. An acetone solution (2 cm^3) of **10** (18.3 mg) was stirred at room temperature for 2 h with MnO_2 (140 mg). The mixture was washed and extracted with acetone to afford **2**, 10.2 mg (57%).

Diels-Alder Reaction of ***2*** *with Cyclopentadiene.* Neat mixture of **2** (78 mg) and freshly prepared cyclopentadiene (1 cm^3) was kept in refrigerator for few d. Silica-gel chromatography of the mixture afforded colorless crystals, mp 111-112.5°C (from MeOH), **13**, 45 mg (42%) [Found: C, 68.17; H, 5.76%. Calcd for $C_{14}H_{14}O_4$: C, 68.28; H, 5.73%. δ(C): 45.0, 46.7, 47.8, 50.3, 56.3, 65.2, 65.5, 110.0, 134.2, 134.5, 136.3, 140.8, 195.5, and 200.7. λ_{max}^{MeOH}: 218 nm (ε=9900), 281 (490), 359 (230)], and colorless crystals, mp 117-118°C (from MeOH), **14**, 31 mg (29%) [Found: C, 68.02; H, 5.75%. δ(C): 44.3, 47.1, 47.7, 52.0, 54.1, 65.4, 66.0, 106.4, 134.3, 135.0, 136.4, 136.7, 201.0, and 202.5. λ_{max}^{MeOH}: 210 nm (ε = 5500, sh), 265 (960), 306 (240)].

Photoreaction of ***2***. *a*) A benzene solution (2 cm^3) of **2** (85.3 mg) was externally irradiated by means of a 400-W high-pressure mercury lamp for 110 min. Silica-gel column chromatography of the mixture yielded a colorless oil (**15**), 46.3 mg (59%) [Found: *m/e*, 198.0543 (M^+). Calcd for $C_9H_{10}O_5$: 198.0528. δ: 2.96 (3H, m), 3.7-3.8 (2H, m), 4.1-4.2 (2H, m), and 7.30 (2H, s). ν: 3460, 1080 cm^{-1}. λ_{max}^{MeOH}: 216 nm (ε = 3800), 264 (4500), 330 (450)], together with the recovered **2** (13.9 mg, 16%).

b) A similar irradiation of **2** (25.6 mg) in MeOH (1.5 cm^3) yielded 15, 11.3 mg (40%).

Photoreaction of ***2*** *with MeOD in Benzene.* A benzene solution (3 cm^3) containing MeOH (40 mg) and **2** (51 mg) was externally irradiated by a high-pressure mercury lamp for 100 min. The photoproduct, **15**-d_1, isolated after silica-gel column chromatography was analyzed by the mass and NMR spectra [Found: *m/e*, 198 : 199=1 : 1.2. δ: 2.96 (2.5H, m), 3.7-3.8 (2H, m), 4.1-4.2 (2H, m), and 7.30 (2H, s)].

Photoreaction of ***1*** *in MeOH. Formation of* ***16*** and ***17***. A MeOH solution (3 cm^3) containing **1** (74 mg) was irradiated by means of a high-pressure mercury lamp for 3.5 h. Silica-gel column chromatography of the mixture afforded a colorless oil, **17**, 20.5 mg (22%) [Found: *m/e*, 168.0423 (M^+). Calcd for $C_8H_8O_4$: 168.0423. δ: 2.8-3.0 (3H, m), 3.60 (3H, s), and 7.30 (2H, s)], and yellow crystals, mp 240°C (dec), 9.5 mg (12%), which was identical with 16.

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7) The NMR spectra were measured in $CDCl_3$ solutions, and the chemical shifts were expressed in δ scale from the internal standard, Me_4Si. In some cases, particular protons were designated as Ha, Hb, Hc, *etc.*, in an order of the chemical shifts (from high field to low field), and they are mutually independent.

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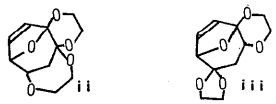
10) Photolysis of **1** (73 mg) in **4** (3 cm^3) gave a colorless oil, **i**, 5.1 mg (5%), but, its NMR [δ: 2.7 (2H, m), 2.9 (2H, m), 4.2-4.5 (4H, m), 6.00 (1H, d, $J=12$ Hz), and 6.58 (1H, d, $J=12$ Hz). δ(C): 29.3, 39.5, 60.5 (2C), 62.6, 124.2, 142.0, 172.0, and 201.5. *m/e*, 154.0647 probably $(M\text{-}CO)^+$). Calcd for $C_8H_{10}O_3$: 154.0631] was different from that of **15**. Due to its difficulty in obtaining the quantity, no further investigation was attempted.

11) This reaction yielded two minor further reaction products with the glycol: **ii**; mp 98.5-101°C, 5 mg (4%) [Found: C, 58.25; H, 6.26%. Calcd for $C_{11}H_{14}O_5$: C, 58.40; H, 6.24%. δ: 1.84 (1H, dm, $J=15.5$ Hz), 2.32 (1H, dd, $J=15.5$, 6 Hz), 3.54 (1H, dm, $J=6$ Hz), 3.6-4.5 (8H, m), 4.60 (1H, t, $J=2$ Hz), 6.09 (1H, d, $J=6$ Hz), and 6.42 (1H, dd, $J=6$, 2.5 Hz)], and **iii**; mp 111-112°C, 2.5 mg (2%) [Found: C, 58.19; H, 6.23%. δ: 1.79 (1H, dd, $J=13$, 10.5 Hz), 2.03 (1H, ddd, $J=13$, 6.5, 1.5 Hz), 3.54 (1H, dd, $J=10.5$, 6.5 Hz), 3.7-4.1 (8H, m), 4.40 (1H, br. s), and 6.55 (2H, s)]. The structures of **ii** and **iii** can be expressed as follows on the basis of spectral evidence and the mechanism of formation.



[Scheme 3]