Generation and Reactions of 5,6-Dimethylene-2-cyclohexene-1,4-diones. A New Synthesis of Polycyclic 1,4-Benzoquinones

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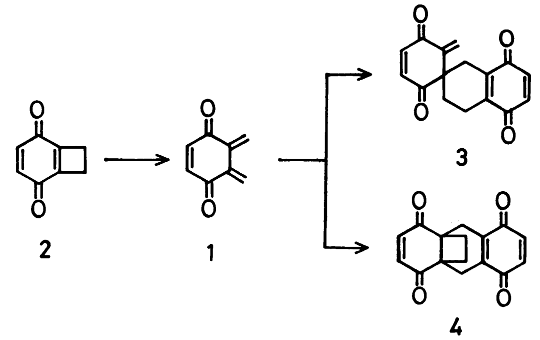
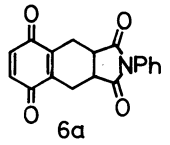
Synopsis. 1,2,3,6-Tetrahydrobenzocyclobutene-3,6-dione underwent thermal ring opening of the four-membered ring at 140 °C to generate 5,6-dimethylene-2-cyclohexene-1,4-dione. This is a highly reactive substance and was trapped as dimers or Diels-Alder adducts giving polycyclic 1,4-benzoquinones. Intramolecular rearrangements preferably took place in some derivatves.

5,6-Dimethylene-1,3-cyclohexadienes (*o*-quinodimethanes) have proved to be useful intermediates in organic syntheses by virtue of their high reactivity in cycloaddition reactions.[1)] Accordingly, 5,6-dimethylene-2-cyclohexene-1,4-dione (**1**) is an interesting compound, since its Diels-Alder reactions with dienophiles would afford polycyclic 1,4-benzoquinones in a single step. Although the intermediary formation and some reactions of 2,3-dimethyl and benzo derivative of **1** have been reported,[2,3)] the parent compound **1** remains unknown. We have recently reported the synthesis of 1,2,3,6-tetrahydrobenzocyclobutene-3,6-dione (**2**) which is considered to be a promising precursor for **1**.[4)] This paper describes the results of thermolysis of **2** and some derivatives in the absence or presence of trapping agents.

Thermal electrocyclic ring opening of the cyclobutene of **2** readily took place at about 140 °C. This temperature is considerably lower than that required for the ring opening of 1,2-dihydrobenzocyclobutene, which ring-opens at about 200 °C,[1a)] probably because there is no loss of aromatic stabilization in the ring opening of **2**. In a typical experiment, heating of a 0.05 M solution of **2** in xylene under reflux for 2 h gave dimers **3** and **4** in 11% and 39% yield, respectively. The ^{1}H NMR spectrum of **3** shows the presence of six olefinic protons including two exocyclic methylene protons and the absence of symmetry, whereas that of **4** shows the presence of four olefinic protons and a mirror plane, supporting the assigned structures. Dimer **3** is thus a Diels-Alder adduct of two molecules of **1**, and dimer **4** is that of **1** and **2**. The predominant formation of **4** is in accord with the high dienophilicity of the strained internal double bond of **2** as previously observed in its Diels-Alder reactions.[5)] As might be expected, **2** gave only **3** under conditions of flash vacuum thermolysis at 350 °C where **2** would rapidly open to **1**.

In the presence of excess of dienophiles (5 equiv.) such as *N*-phenylmaleimide (**5a**), dimethyl fumarate (**5b**), 1,4-naphthoquinone (**5c**), and acenaphthylene (**5d**) **1** could form adduct **6a** (29%), **6b** (47%), **6c** (11%), and **6d** (28%), respectively. The yields were, however, poor to moderate due to the competition of the dimerization forming **4**. In the case of **5c**, the primary Diels-Alder adduct was apparently further oxidized to **6c** under the reaction conditions. Although hydrocarbon **5d** could form adduct **6d**, other simple olefins such as indene and cyclooctene failed to form adducts giving only the dimers.

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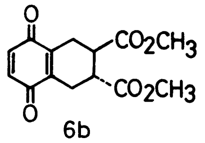
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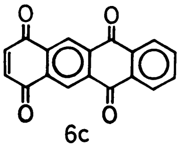
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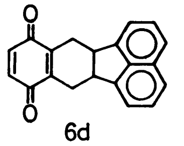
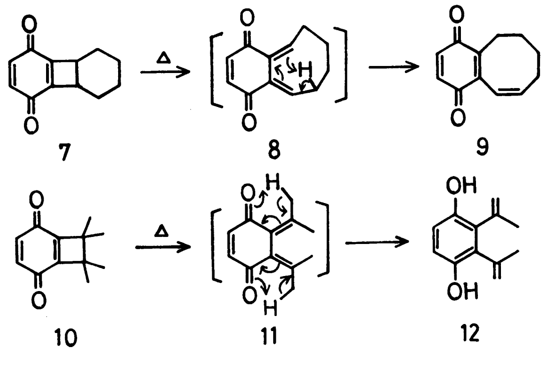

6d

When alkyl groups are present on the four-membered ring, intramolecular rearrangements become feasible in the ring-opened form and were actually observed to take place. Thermolysis of 1,4,4b,5,6,7,8,8a-octahydrobiphenylene-1,4-dione (**7**) at 140 °C gave 1,4,7,8,9,10-hexahydrobenzocyclooctene-1,4-dione (**9**) in 72% yield. The rearrangement can be accounted for in terms of conrotatory ring opening to a (*E*,*Z*)-cyclooctadiene **8** followed by [1,5] sigmatropic hydrogen shift. A molecular model of **8** suggests the favorable spatial location of a methylene proton for the hydrogen shift. On the other hand, 1,1,2,2-tetramethyl derivative **10** gave 2,3-diisopropenylhydroquinone (**12**) in 51% yield. The formation of **12** can be rationalized by a double [1,5] sigmatropic hydrogen shift involving the carbonyl groups in the ring-opened form **11**.



Experimental

All the melting points were determined on either a Yamato MP-21 or a Mettler FP-2 apparatus and are uncorrected. Infrared spectra were recorded with a Hitachi 215 grating spectrophotometer, and electronic absorption spectra with a Hitachi 323 spectrophotometer. ^{1}H NMR spectra were obtained with either a JNM-PMX 60 or a JNM-FX90Q spectrometer using $(CH_3)_4Si$ as an internal standard. Mass spectra were measured with a Hitachi M-52 mass spectrometer. Merck Kieselgel 60 was used for column chromatography.

*Thermolysis of 1,2,3,6-Tetrahydrobenzocyclobutene-3,6-dione (**2**) in the Absence of Trapping Agent.* A solution of **2** (268 mg, 2 mmol) in xylene (10 ml) was heated under reflux under a nitrogen atmosphere for 2 h. After evaporation of the solvent, the residue was chromatographed on silica gel (50 g) and eluted with benzene–ethyl acetate (95:5). The first yellow band gave **3** (31 mg, 11.5%) and the second yellow band **4** (150 mg, 39%). **3**: Yellow crystals from dichloromethane–hexane, mp 147—149 °C. MS m/z (rel intensity) 268 (M$^+$; 100), 240 (61); IR (KBr)1684, 1670, 1640, 1598 cm^{-1}; UV (EtOH) λ_{max} 240 (log ε 4.32), 338 nm (2.97); ^{1}H NMR (CDCl$_3$) δ 1.95 (2H, dd, J=6, 7 Hz), 2.47 (2H, m), 2.86 (1H, m), 3.20 (1H, m), 5.29 (1H, s), 6.18 (1H, s), 6.78 (2H, s), 6.79 (1H, d, J=10.4 Hz), 6.97 (1H, d, J=10.4 Hz); Found: C, 71.25; H, 4.52%. Calcd for $C_{16}H_{12}O_4$: C, 71,63; H, 4.51%. **4**: Yellow crystals from dichloromethane–hexane, mp 204—205 °C; MS m/z 268 (M$^+$, 13), 240 (100); IR (KBr) 1662, 1648, 1600, 1292, 824 cm^{-1}; UV (EtOH) λ_{max}=225 (log ε 4.22), 240 (4.19), 248 (4.19), 340 nm (2.88); ^{1}H NMR (CDCl$_3$) δ=2.13 (4H, m), 2.36 (2H, d, J=16.4 Hz), 3.37 (2H, d, J=16.4 Hz), 6.87 (2H, s), 6.91 (2H, s); Found: C, 71.57; H, 4.46%. Calcd for $C_{16}H_{12}O_4$: C, 71.63; H, 4.51%.

Flash Vacuum Thermolysis of **2**. Sublimatively vapourized **2** (51 mg) was passed through a preheated quartz column (15×200 mm) packed with Pyrex glass chips at 350 °C at 0.5 mmHg. The pyrolysate was led into a receiver cooled at 0 °C, but yellow solids condensed on the inside of the wall of the column just out the electronic furnace. After cooling to room temperature the condensate was washed out with dichloromethane into the receiver. The solvent was evaporated and the residue chromatographed on silica gel to give **3** (14 mg, 27%).

General Procedure for the Trapping Experiments with Dienophiles. Solutions of **2** (134 mg, 1 mmol) and a dienophile (5 mmol) in xylene (10 ml) were heated under reflux under a nitrogen atmosphere for 2 h. After evaporation of the solvent the residue was chromatographed on silica gel and eluted with benzene–ethyl acetate.

(a) With N*-Phenylmaleimide*: Unreacted *N*-phenylmaleimide (742 mg), dimer **4** (32 mg, 24%), and adduct **6a** (90 mg, 29%) were obtained. **6a**: Yellow crystals from benzene–dichloromethane, mp 243—244 °C; IR (KBr) 1700, 1644, 1590, 1386, 1180 cm^{-1}; ^{1}H NMR (CDCl$_3$–CD$_3$SOCD$_3$) δ=2.7—3.2 (4H, m), 3.3—3.6 (2H, m), 6.87 (2H, s), 7.1—7.6 (5H, m); Found: C, 70.16; H, 4.12; N, 4.49%. Calcd for $C_{18}H_{13}NO_4$: C, 70.35; H, 4.26; N, 4.56%.

(b) With Dimethyl Fumarate: Unreacted dimethyl fumarate (580 mg), adduct **6b** (130 mg, 47%), and dimer **4** (30 mg, 22%) were obtained. **6b**: Yellow crystals from dichloromethane–hexane, mp 91—92 °C; IR (KBr) 1730, 1655, 1600, 1305, 1232 cm^{-1}; ^{1}H NMR (CDCl$_3$) δ=2.6—3.3 (6H, m), 3.77 (6H, s), 6.78 (2H, s); Found: C, 60.37; H, 5.13%. Calcd for $C_{14}H_{14}O_6$: C, 60.43; H, 5.07%.

(c) With 1,4-Naphthoquinone: Unreacted naphthoquinone (686 mg) and adduct **6c** (30.5 mg, 11%) were obtained. **6c**: Deep yellow crystals from benzene–dichloromethane, mp 261—262 °C (lit.[6] 262 °C).

(d) With Acenaphthylene: Unreacted acenaphthylene, adduct **6d** (79 mg, 28%), and dimer **4** (15 mg, 11%) were obtained. **6d**: Yellow crystals from dichloromethane, mp 176—177 °C; IR (KBr) 1645, 1590, 1325, 1290, 783 cm^{-1}; ^{1}H NMR (CDCl$_3$) δ=2.6—3.4 (4H, m), 4.10 (2H, m), 6.61 (2H, s), 7.2—7.8 (6H, m); Found: C, 83.88; H, 4.77%. Calcd for $C_{20}H_{14}O_2$: C, 83.90; H, 4.93%.

*Thermal Rearrangement of 1,4,4b,5,6,7,8,8a-Octahydrobiphenylene-1,4-dione (**7**)*: A solution of **7** (90 mg) in xylene (10 ml) was heated under reflux under a nitrogen atmosphere for 5 h. After evaporation of the solvent, the residue was chromatographed on silica gel (3 g) and eluted with hexane–ethyl acetate (9:1) to give **9** (65 mg, 72%); yellow crystals from dichloromethane–hexane, mp 59—60 °C; IR (KBr) 1650 1590, 1300, 855 cm^{-1}; UV (cyclohexane) λ_{max}=249 (log ε 4.20), 368 (3.25), 439 sh (2.34), 460 sh (2.09), 492 sh nm (1.64); ^{1}H NMR (CDCl$_3$) δ=1.60 (4H, m), 2.21 (2H, m), 2.63 (2H, m), 6.02 (1H, dd, J=12.0, 5.4 Hz), 6.26 (1H, d, J=12.0 Hz), 6.71 (2H, s); Found: C, 76.72; H, 6.51%. Calcd for $C_{12}H_{12}O_2$: C, 76.57; H, 6.43%.

*Thermal Rearrangement of 1,1,2,2-Tetramethyl-1,2,3,6-tetrahydrobenzocyclobutene-3,6-dione (**10**)*: A solution of **10** (150 mg) in xylene (10 ml) was heated under reflux under a nitrogen atmosphere for 1 h. After evaporation of the solvent the residue was chromatographed on silica gel (15 g) and eluted with hexane–ethyl acetate (92:8) to give **12** (112 mg, 74.5%); colorless crystals from hexane–ethyl acetate, mp 119—121 °C; IR (KBr) 3240, 1640, 1610, 1340, 1290, 878, 809 cm^{-1}; ^{1}H NMR (CDCl$_3$–CD$_3$OD) δ=2.04 (6H, s), 4.97 (2H, br. s), 5.35 (2H, br. s), 6.70 (2H, s); Found: C, 75.49; H, 7.52%. Calcd for $C_{12}H_{14}O_2$: C, 75.76: H, 7.42%.

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