Notes

Practical Synthesis of Semibullvalene[1]

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Semibullvalene was first synthesized by Zimmerman and Grunewald in 1966[2] by the sensitized irradiation of barrelene.[3] Although straightforward, the synthesis requires six steps to reach barrelene. Since that time, four additional syntheses of semibullvalene have been reported.

Thus, a second synthesis was described simultaneously by Meinwald[4] and Zimmerman.[5] This involved the room-temperature thermal rearrangement of tricyclo-[3.3.0.0^{2,6}]octa-3,7-diene to semibullvalene. The unstable diene is obtained by photochemical intramolecular [2 + 2] cycloaddition of 1,5-cyclooctadiene[6] followed by free-radical chlorination to afford a dichloride which was dehydrochlorinated. The method is practical but limited by 25–40% yields in the several steps.

A third synthesis[7] utilized the sensitized photolysis of 2,3-diazotetracyclo[4.4.0.0^{4,10}.0^{5,7}]deca-2,8-diene[7] which was obtained in three steps from barrelene. An alternative route to the diazatetracyclic precursor has been described by Askani.[8] This alternative used five steps from cyclooctatetraene.

A fourth synthesis using cyclooctatetraene and diethyl azodicarboxylate and requiring five synthetic steps led to semibullvalene in 24% yield.[9]

The last synthesis[10] utilized the irradiation of cyclooctatetraene at –50 °C. While of preparative value, the method afforded benzene as an appreciable byproduct. Higher temperature solution-phase photolysis did not lead to semibullvalene.

Results and Discussion

A very practical synthesis of semibullvalene was found in the vapor-phase irradiation of cyclooctatetraene[11] (eq

1). The method is one of simplicity and essentially
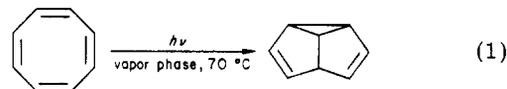
quantitative yield. The main requisites of the synthesis are (1) a light source about 300 nm where cyclooctatetraene but not the semibullvalene product absorbs and (2) experimental conditions where reactant cyclooctatetraene is not permitted to absorb ultraviolet light while a liquid. Either a 450-W Hanovia lamp with a Pyrex filter or a Rayonet-type apparatus with 350 ± 30-nm lamps may be used. The extent of product formation is limited only by the total amount of light utilized and thus by the reaction time.

Our earlier publication[10] presents an extended discussion of mechanistic pathways leading to semibullvalene from cyclooctatetraene, and the present publication primarily contributes synthetically.

Experimental Section

Three 100-mL, one-necked flasks with 24/40 ground-glass joints and a 4-L beaker (25 cm high and 18 cm in diameter) are employed for the photolysis. The source of ultraviolet is a Hanovia 450-W, medium-pressure, mercury lamp and immersion-well apparatus. A Pyrex filter cylinder is used around the lamp to filter out wavelengths below 300 nm.

Into each flask is added 100 mg (0.96 mmol) of cyclooctatetraene. Each flask is sealed under vacuum by first being cooled in a dry ice/acetone bath followed by subsequent application of a 0.05-mm vacuum. The lamp well is immersed in the center of the beaker filled with water maintained at 70 °C. The beaker is surrounded by aluminum foil which serves as a reflector. The flasks containing the cyclooctatetraene are placed in the water in proximity to the lamp well and irradiated for 60 h at 70 °C.

After termination of photolysis, the product is distilled to the bottom of each flask by application of a dry ice/acetone bath to the flask bottoms, followed by removal by pipet. The total crude product weighs 0.26 g and is found by 100-MHz NMR and IR (CHCl$_3$ solution) analyses to consist of ≥98% semibullvalene, with traces (<2%) of benzene and cyclooctatetraene.

Alternatively, the photolysis can be carried out in a Rayonet apparatus equipped with 12 RPR 3500-Å lamps. A cylindrical Pyrex vessel, 25 cm long and 11 cm in diameter, fashioned with a 10-mm cold finger at the bottom and a glass joint at the other end, was employed for the photolysis.

A charge of 0.27 g (2.6 mmol) of cyclooctatetraene is added to the cold finger. The charge is cooled with a dry ice/acetone solution, and the vessel is sealed under vacuum (0.05 mm). The vessel is positioned at the center of the Rayonet reactor which is wrapped with aluminum foil. The sample is irradiated for 60 h at the temperature achieved by the heat generated by the lamps (~70 °C). After termination of photolysis, the product is condensed in the cold finger by application of a dry ice/acetone solution, and the cold finger is cut off the reaction vessel. The product obtained weighs 0.24 g and is found by NMR analysis to consist of >98% semibullvalene, with traces of benzene (<1%) and cyclooctatetraene (<1%).

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(3) (a) Zimmerman, H. E.; Paufler, R. M. *J. Am. Chem. Soc.* **1960**, *82*, 1514–1515. (b) Zimmerman, H. E.; Grunewald, G. L.; Paufler, R. M.; Sherwin, M. A. *Ibid.* **1969**, *91*, 2330–2338.
(4) Meinwald, J.; Schmidt, D. *J. Am. Chem. Soc.* **1969**, *91*, 5877.
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(8) Askani, R.; Gurang, I.; Schwertfeger, W. *Tetrahedron Lett.* **1975**, 1315–1318.
(9) (a) Askani, R. *Tetrahedron Lett.* **1970**, 3349–3350. (b) Note a similar approach by: Paquette, L. A. *J. Am. Chem. Soc.* **1970**, *92*, 5765–5767. This affords a 47% yield beginning with the formal adduct of *N*-phenyltriazolinedione and cyclooctatetraene.
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A New Synthesis of Anthraquinones

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As part of a program to synthesize naturally occurring quinones such as frenolicin[1] and the nanaomycins,[2,3] diethyl glutaconate was reacted with 2-butyryl-1,4-naphthoquinone in order to elaborate the dihydropyran ring system. Instead of dihydropyran formation the anthraquinone **2** (Scheme I) was found. This discovery amounts to a new annelation procedure for the synthesis of anthraquinones.

The synthesis of 2-butyryl-1,4-naphthoquinone is summarized in Scheme I. The Fries rearrangement of the dibutyrate **3** followed by hydrolysis of the rearranged ester and oxidation of the naphthalenediol **4** with silver carbonate adsorbed on Celite gave **1**.

The structural assignment of **2** was based on spectral data. The mass spectrum of **2** displayed an intense molecular ion at m/e 349 and ions at m/e 365 (loss of CH_3CH_2 from the propyl side chain) and 349 (loss of CH_3CH_2O from one of the carbethoxyl groups). The ^1H NMR spectrum in CCl_4 gave an AA'BB' pattern centered at 7.9 ppm and a singlet at 7.75 ppm. The ester methylene hydrogens appeared as overlapping quartets centered at 4.45 and 4.40 ppm and the propyl methylene hydrogens adjacent to the benzene ring appeared as a triplet centered at 3.35 ppm. The ^{13}C NMR spectrum showed four carbonyls at 184 and 182.5 (quinone carbonyls) and 169 and 167 ppm (ester carbonyls). The ester and propyl methylenes as well as the three methyl resonances occurred as expected.

The formation of **2** can be rationalized according to Scheme II. The base-catalyzed addition of diethyl glutaconate to **1** gave the anion **5** which subsequently underwent proton transfer to produce the anion **6**. The anion **6** condensed intramolecularly with loss of water to form the anthrahydroquinone **7** which was probably air oxidized to the quinone **2**. The anion **6** may also transfer hydride to unreacted **1** to form a quinone which could lose a proton to form an anion capable of condensation with the acyl carbonyl to give the anthraquinone **2**. The former scheme seems more likely because proton-transfer reactions such as those involved in the conversion of **6** to **7** are expected to be faster than bimolecular hydride-transfer reactions.

In summary, this annelation reaction should provide new methodology for the future synthesis of anthraquinones.

Experimental Section

All melting and boiling points are uncorrected. Infrared spectra were recorded with a Perkin-Elmer IR-237. Mass spectra were taken on a single-focusing Hitachi RMU-6 spectrometer while proton NMR spectra were run with a JEOL-C-60M spectrometer
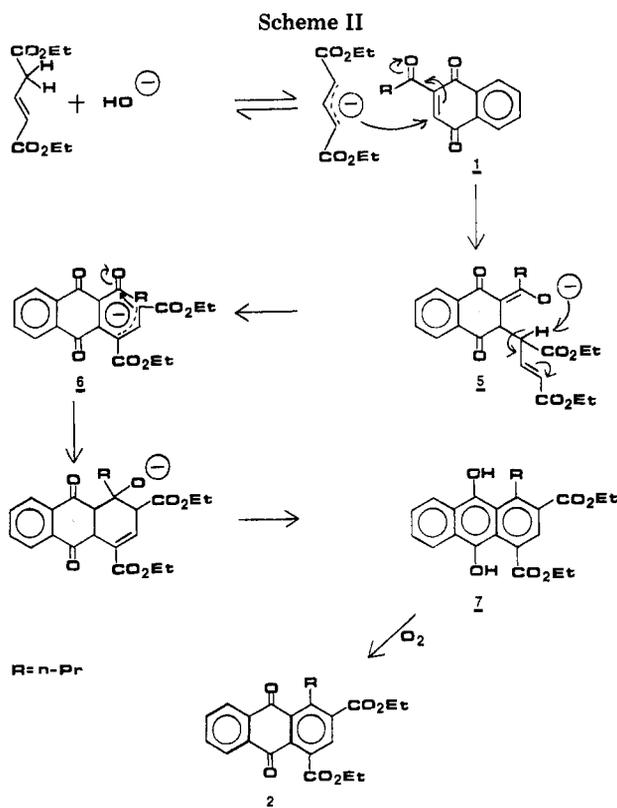
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Scheme I
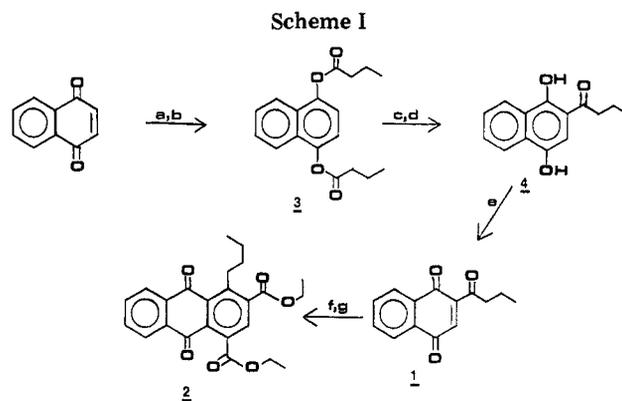
^{a} a, $Na_2S_2O_4$; b, $(CH_3CH_2CH_2CO)_2O$, H_2SO_4; c, $AlCl_3$; d, CH_3OH/HCl, then H_2O; e, $Ag_2CO_3/Celite$; f, diethyl glutaconate/NH_4OH; g, O_2.

Scheme II

R= n-Pr

and carbon-13 NMR were taken on a Bruker WH-90 with Me_4Si as an internal standard. Microanalysis was performed by Galbraith Laboratories, Inc.

1,4-Naphthalenediol Dibutyrate (3). To a flask containing 79.1 g (0.5 mol) of 1,4-naphthoquinone, previously recrystallized from acetone several times, and 500 mL of water was added 115 g (0.66 mol) of sodium hydrosulfite. The mixture was stirred for 2 h under N_2 and then extracted five times with 100 mL of ether. The ether extracts were combined and the ether was evaporated under vacuum. The crude naphthohydroquinone was dried under high vacuum (2.0 × 10^{-4} mm) for several days in the dark and was reacted with 158.2 g (1.0 mL) of butyric anhydride and 2 drops of concentrated H_2SO_4. The mixture was heated for 2 h under N_2 on a steam bath, and after cooling the crude ester was crystallized by the addition of a methanol–water solution. The solid was distilled and the fraction boiling at 184–189 °C (2.5 × 10^{-2} mm) was recrystallized from methanol to give 120.1 g (78%) of the white diester: mp 47–48 °C (lit.[4] mp 41–42 °C); ^1H NMR (CCl_4) δ 0.98 (9 H, t), 1.75 (4 H, m), 2.50 (4 H, t), 7.05 (2 H, s), 7.48 (4 H, m); IR (neat) 1760 cm^{-1}; mass spectrum, m/e 300, 231, 162, 144, 132, 115, 102, 71, 55, 43.

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