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Preparation and Pyrolysis of Some 2,6-Dimethyl-4-pyrone–Alkyne Photoadducts. Bicyclic Claisen Rearrangement

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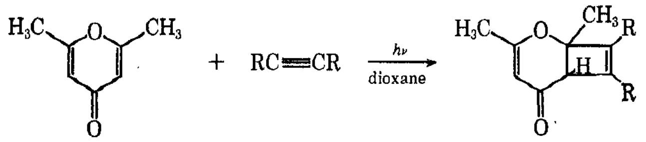
The photoaddition reaction of 2,6-dimethyl-4-pyrone with acetylenes has produced the desired 1:1 photoadducts. The pyrolysis of these cyclobutene derivatives was carried out in an attempt to convert them to the oxacyclooctatrienone ring system. However, the adducts underwent a symmetry-allowed bicyclic Claisen rearrangement followed by aromatization to substituted phenols.

Several examples of addition reactions of photochemically excited molecules to substituted acetylenes to produce cyclobutene derivatives have been reported in the literature.[1-3] The photoaddition reaction of 2-cyclopentenone with butyne-2 was the first reported example of this type reaction.[1] Recently we have shown that chromone undergoes a similar photoaddition with butyne-2.[4,5]

We would now like to report the unsensitized photoaddition reaction of 2,6-dimethyl-4-pyrone with substituted acetylenes to produce the cyclobutene derivatives. The purpose of this work was to prepare these 1:1 adducts in the hope that they would serve as useful intermediates in the preparation of medium-sized oxygen heterocycles. The results of pyrolysis experiments carried out on the photoadducts are described.

Results

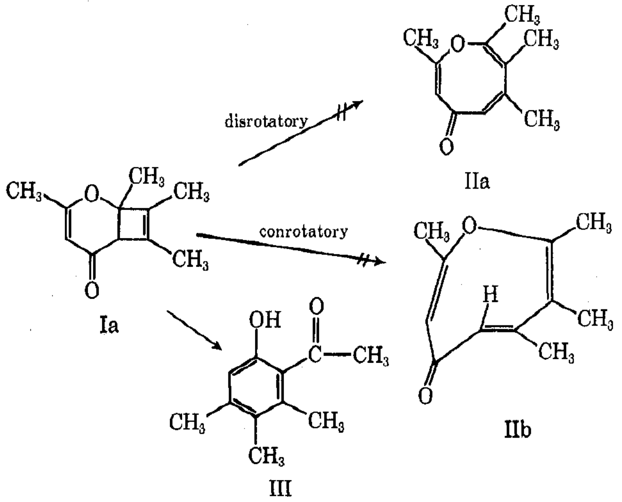
A solution of 2,6-dimethyl-4-pyrone, butyne-2, and dioxane was irradiated with the 450-W mercury arc lamp. Gas–liquid chromatography indicated that only one major product was produced. The major product was isolated by liquid-liquid partition chromatography (llpc) and shown to be the desired 2,6-dimethyl-4-pyrone–butyne-2 adduct (Ia) by nmr, ir, uv, and mass spectral analysis.



Ia, R = CH_3
b, R = CH_3

The pyrolysis of Ia was undertaken in an attempt to convert it to the *cis,cis,cis*-oxa-2,5,7-cyclooctatrien-4-one ring system, IIa. Such a ring opening would have to occur by a symmetry-forbidden disrotatory mode, or by a heterolytic or homolytic pathway, all of which are predicted to require highly energetic conditions. It was hoped that the reaction might occur under the forcing conditions of high temperature since the allowed conrotatory opening of the cyclobutene ring should be very difficult due to the formation of a trans double bond in the product, *cis,trans,cis*-oxa-2,5,7-cyclooctatrien-4-one (IIb).

The pyrolysis of adduct Ia was accomplished by refluxing in *o*-dichlorobenzene for 2 days. By glpc it was shown that one major and one very minor product were formed during the pyrolysis. The major product isolated by llpc was identified as 2-acetyl-3,4,5-trimethylphenol (III). The structure of this product was determined by nmr, ir, uv, mass spectrum, and comparison with an authentic sample prepared by an independent route.[6]



One can envision two different pathways for the pyrolysis reaction leading to the formation of III. In order to distinguish between these two different pathways, it was necessary to carry out the pyrolysis of the **2,6-dimethyl-4-pyrone–hexyne-3 adduct (Ib)**. The preparation of Ib was carried out *via* the photoaddition reaction and its structure determined by nmr, ir, uv, and mass spectrum.

Path a involves initial cleavage of the ether oxygen–C_8 bond to give the diradical intermediate IV. This is followed by bond formation between C_3 and C_8

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[1] P. E. Eaton, *Tetrahedron Lett.*, 3695 (1964).

[2] R. Criegee, U. Zirngibl, H. Furrer, D. Seebach, and G. Freund, *Chem. Ber.*, **97**, 2942 (1964).

[3] G. O. Schenck and R. Steinmetz, *Bull. Soc. Chim. Belg.*, **71**, 781 (1962).

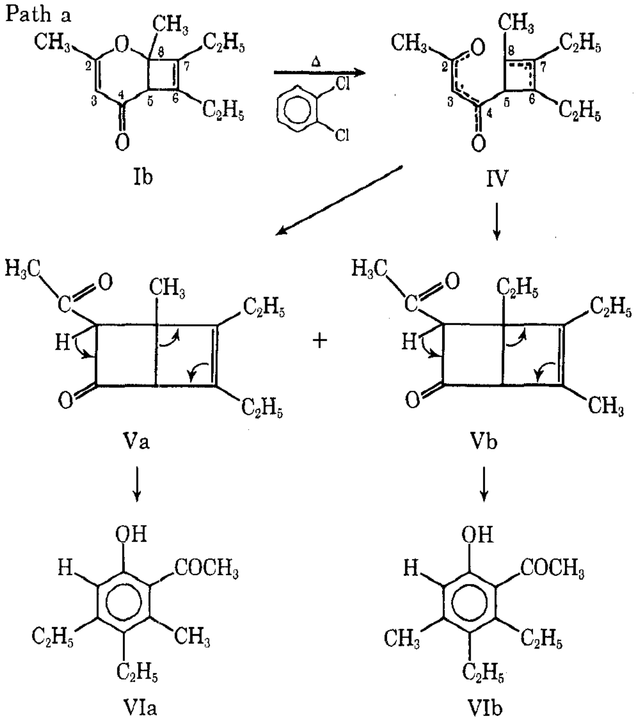
[4] J. W. Hanifin and E. Cohen, *Tetrahedron Lett.*, 5421 (1966).

[5] J. W. Hanifin and E. Cohen, *J. Amer. Chem. Soc.*, **91**, 4494 (1969).

[6] An authentic sample of 2-acetyl-3,4,5-trimethylphenol was obtained *via* a Fries rearrangement on 3,4,5-trimethylphenyl acetate.

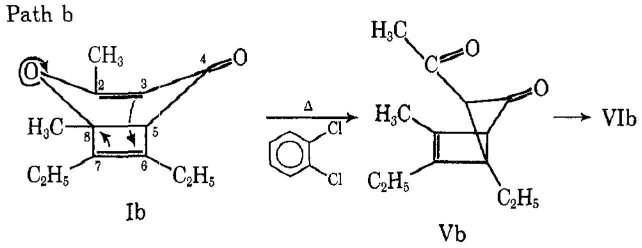
or C_3 and C_6 to give Va and Vb, respectively. Rearrangement of Va and Vb followed by enolization should yield the two isomer phenols VIa and VIb.

Path a

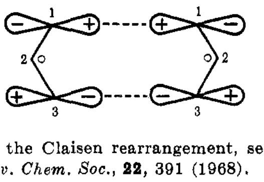


Path b involves the concerted intramolecular conversion of Ib to Vb by a reaction mechanism analogous to the Claisen rearrangement,[7] the thermal transformation of an allyl vinyl ether to a homoallylic carbonyl compound. Rearrangement and enolization of Vb would give only the phenol VIb.

Path b



The Claisen and Cope rearrangements have recently been classified by Woodward and Hoffman[8] as sigmatropic changes of the order $[i,j]$ where i and j corresponds to 3. It can be shown by use of the phase relationships of the highest occupied molecular orbital that for rearrangements of the order $[i,j]$ in which both i and j are greater than unity, thermal changes are symmetry-allowed when $i + j = 4n + 2$. If it is assumed that the Cope rearrangement proceeds by formation and combination of allyl quasiradicals in the transition state, the picture of the highest occupied molecular orbitals shows that the [3,3] change



is allowed. Experimentally, it has been shown that the conclusions are the same for the Claisen rearrangement.[9]

This picture is in agreement with the stereochemical requirements for intramolecular allylic rearrangements which demand that bond breaking and bond formation both occur on the same face of the allyl group, classifying it is a suprafacial migration.

The pyrolysis of Ib was carried out and the reaction products examined by glpc and llpc. It was shown that only one phenol was produced. This product, isolated by llpc, was positively identified as VIb by nmr, ir, uv, and mass spectral analysis. The nmr spectrum contained two methyl groups at δ 1.13 and 1.22 (triplets, $J = 7$ cps), one aromatic methyl at δ 2.32 (doublet, $J = 0.3$ cps), one acetyl methyl at δ 2.66 (singlet), two methylene groups at δ 2.62 (quartet, $J = 7$ cps) and 2.85 (quartet, $J = 7$ cps), one aromatic hydrogen at δ 6.62 (quartet, $J = 0.3$ cps), and one broad phenolic hydrogen at δ 9.50. Double irradiation experiments were carried out on VIb such that strong irradiation of the aromatic hydrogen collapsed the aromatic methyl to a singlet.[10] The ir spectrum contained the expected absorption bands at 3.03 and 5.96 μ, analogous to III. The uv spectrum showed absorption maxima at 219, 260, and 290 mμ, again analogous to III. The mass spectrum gave the expected molecular ion at *m/e* 206. This experiment indicates that the reaction proceeds *via* path B.[11]

In conclusion, pyrolysis of the 2,6-dimethyl-4-pyrone–alkyne photoadducts yields a 2-acetyl-3,4,5-trialkylphenol *via* path b, a concerted reaction analogous to the Claisen rearrangement.

Experimental Section

Procedure for Photoaddition Reactions.—The photoaddition reactions were carried out using the immersion apparatus supplied by the Hanovia Lamp Division of Engelhard Industries. This consisted of an irradiation vessel fitted with a water-cooled quartz immersion well, magnetic stirring bar, and a side arm connected to a mercury seal. A freshly prepared solution of the reactants to be irradiated was added to the vessel and then the solution was flushed with nitrogen for several minutes. The irradiation vessel was immersed in a large beaker of water for additional cooling. The solution was irradiated with a 450-W, medium-pressure mercury arc, type no. 679A-10.

The course of the reaction was followed by removing samples from the irradiation vessel and examining them by gas–liquid chromatography. The F & M Model 720 gas chromatograph fitted with a 6-ft 20% silicon rubber Se-30 column was used for the analysis.

Spectra.—Nmr spectra were determined on a Varian A-60 spectrometer using tetramethylsilane as an internal standard. Infrared spectra were determined on a Perkin-Elmer Infracord spectrophotometer. Ultraviolet spectra were measured on a Cary Model 11 MS spectrophotometer. Mass spectra were determined on a AEIMS9 mass spectrometer. Melting points were determined in a capillary tube in a Mel-Temp apparatus and are uncorrected.

Materials.—2,6-Dimethyl-4-pyrone from Aldrich Chemical Co. was used without further purification. Butyne-2 and hexyne-3 from Farchan Research Laboratories were also used without

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[7] For a review of the Claisen rearrangement, see A. Jefferson and F. Scheinmann, *Quart. Rev. Chem. Soc.*, **22**, 391 (1968).

[8] R. B. Woodward and R. Hoffmann, *J. Amer. Chem. Soc.*, **87**, 2511, 4389 (1965).

[9] Y. Pocker, *Proc. Chem. Soc., London*, 141 (1961).

[10] Double irradiation experiments were also conducted on III. The results served to verify our nmr analysis of VIb.

[11] Some additional evidence for the proposed mechanism was obtained from the pyrolysis of Ia which yielded a minor product along with III. Only a trace amount of this product could be obtained as an impure oil; however, its ir spectrum contained two carbonyl bands at 5.65 and 5.85 μ, suggestive of the bicyclo[2.2.0]hex-5-en-2-one system V. The mass spectrum of the material gave a molecular ion at *m/e* 170.

further purification. Dioxane from Matheson Coleman and Bell was purified by distillation from the sodium ketyl of benzophenone and stored frozen under nitrogen.

1,3,7,8-Tetramethyl-2-oxabicyclo[4.2.0]octa-3,7-dien-5-one (2,6-Dimethyl-4-pyrone–Butyne-2 Adduct) (Ia).—A solution of 0.08 mol of 2,6-dimethyl-4-pyrone, 1.85 mol of 2-butyne, and 1.14 mol of dioxane was prepared. This solution was then added to the outer jacket of the 450-W mercury arc immersion apparatus. The solution was flushed with nitrogen for several minutes and irradiation begun. The course of the reaction was followed by gas–liquid partition chromatography using the 6-ft 20% SE-30 column at 220°. After 48 hr the irradiation was stopped. By glpc and llpc it was shown that the 1:1 adduct was the only major product. Some white crystals which precipitated to the bottom of the flask were filtered and shown to be the known dimer. The volatile materials were removed on the rotating evaporator; the product was isolated by llpc using a heptane–methanol system. The infrared spectrum of the adduct showed strong carbonyl absorption at 6.1 μ. The nmr spectrum contained one methyl group at δ 1.53 (singlet), two vinyl methyl groups at δ 1.62 (multiplet), one vinyl methyl group at δ 1.95 (singlet), one tertiary hydrogen at δ 3.02 (multiplet), and one vinyl hydrogen at δ 5.15 (singlet). The uv spectrum of this product showed $\lambda_{\max}^{\mathrm{MeOH}}$ 273 mμ (ϵ 7700). The mass spectrum of the compound gave a molecular ion at *m/e* 178.

Anal. Calcd for $C_{11}H_{14}O_2$: C, 74.1; H, 7.9. Found: C, 73.5; H, 8.2.

2-Acetyl-3,4,5-trimethylphenol (III).—To 8.0 g (0.045 mol) of 3,4,5-trimethylphenyl acetate was added 6.0 g (0.045 mol) of aluminum chloride. This mixture was shaken together and then heated to 130° in an oil bath. After cooling, the contents of the flask were added to a mixture of 30 g of ice and 15 ml of concentrated hydrochloric acid. A yellow oil formed which was extracted with ether. The ether solution was dried over calcium chloride and then the ether was removed. The residue was taken up in hot petroleum ether (bp 30–60°) and approximately 4.0 g of product was obtained on cooling. The product was further purified by llpc and recrystallized again from petroleum ether to give a white solid, mp 58–60°. The mass spectrum of the compound showed a molecular ion at *m/e* 178. The infrared spectrum of the product contained carbonyl absorption at 5.94 μ and strong hydroxyl absorption at 3.0 μ. The uv spectrum showed $\lambda_{\max}^{\mathrm{MeOH}}$ 218, 258, and 290 mμ. The nmr spectrum contained three aromatic methyl groups at δ 2.12, 2.25, and 2.40, one methyl group at δ 2.57, one aromatic hydrogen at δ 6.63, and one phenolic hydrogen at δ 10.70.

Anal. Calcd for $C_{11}H_{14}O_2$: C, 74.1; H, 7.9. Found: C, 74.4; H, 8.1.

2-Acetyl-3,4,5-trimethylphenol (III) *via* Pyrolysis of Ia.—A solution of 0.5 g (0.003 mol) of Ia in 3.5 ml of *o*-dichlorobenzene was heated to reflux. The course of the pyrolysis was followed by glpc using the 6-ft 20% SE-30 column at 200°. After refluxing for 72 hr, it was shown that no starting material remained. By glpc it was shown that one major and one minor product were formed during the pyrolysis. The *o*-dichlorobenzene was removed on the spinning band. The two products were then isolated by llpc. The major product was identified as 2-acetyl-3,4,5-trimethylphenol. The structure of this product was determined by comparison of its spectral data with that from the authentic sample prepared by the independent route above. The minor product could only be isolated as an impure oil. Attempts to further purify it were unsuccessful. The mass spectrum of the compound showed a molecular ion at *m/e* 178. The infrared spectrum contains two strong carbonyl bands at 5.65 and 5.85 μ, suggestive of the bicyclo[2.2.0]hex-5-en-2-one system.

7,8-Diethyl-1,3-dimethyl-2-oxabicyclo[4.2.0]octa-3,7-dien-5-one (2,6-dimethyl-4-pyrone–Hexyne-3 Adduct) (Ib).—A solution of 10.0 g (0.08 mol) of 2,6-dimethyl-4-pyrone, 100 g (1.2 mol) of 3-hexyne, and 150 ml of dioxane was prepared and added to the outer jacket of the immersion apparatus. The solution was flushed with nitrogen and irradiation begun. After 24 hr of irradiation, the solution was examined by glpc using the 6-ft 20% SE-30 column at 220°. It was seen that the desired adduct was present in a large yield and that little starting material remained. The volatile materials were removed on the rotating evaporator and the product was isolated by llpc using a heptane–Methyl Cellosolve system. The infrared spectrum of the product showed strong absorption bands at 6.05 and 6.20 μ. The nmr spectrum contained two methyl groups at δ 1.08 (triplets, $J = 7$ cps), one methyl group at δ 1.58 (singlet), one vinyl methyl group at δ 1.95 (singlet), two groups of methylene hydrogens centered at δ 2.12 (multiplet), one tertiary ring hydrogen at δ 3.10 (multiplet), and one vinyl hydrogen at δ 5.18 (singlet). The mass spectrum of the compound showed a molecular ion at *m/e* 206.

Anal. Cacld for $C_{13}H_{18}O_2$: C, 75.7; H, 8.8. Found: C, 76.0; H, 9.4.

2-Acetyl-3,4-diethyl-5-methylphenol (VIb) *via* Pyrolysis of Ib.—A solution of 0.15 g (0.001 mol) of Ib and 5 ml of *o*-dichlorobenzene was heated to reflux. The course of the reaction was followed by glpc, using the 6-ft 20% SE-30 column at 220°. After refluxing for 72 hr, it was shown that no starting material remained. The *o*-dichlorobenzene was removed by distillation and the product was isolated by llpc using a heptane–methanol system. By glpc and llpc it was shown that only one phenol was produced. The infrared spectrum of the product showed strong absorption bands at 3.03, 5.96, and 6.26 μ. The uv spectrum showed $\lambda_{\max}^{\mathrm{MeOH}}$ 219, 260, and 290 mμ. The mass spectrum gave a molecular ion at *m/e* 206.

Registry No.—Ia, 27192-99-0; Ib, 27192-98-9; III, 27192-97-8; VIb, 27193-00-6; 2,6-dimethyl-4-pyrone, 1004-36-0.

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