

Tetrahedron Letters 39 (1998) 3643-3646

TETRAHEDRON LETTERS

Generation and Intramolecular Cyclization of (2-Ethenylphenyl)bisketenes. Synthesis of Benzofuranones

Matthew J. Heileman and Harold W. Moore*

Department of Chemistry

University of California

Irvine CA 92697

Received 2 February 1998; accepted 11 March 1998

Abstract : Several new differentially substituted cyclobutenediones **4a-e** have been prepared. Their thermal rearrangement to substituted naphthofuranones **5a-d** is reported. This rearrangement involves an unprecedented intramolecular cyclization of a reactive bisketene **6**, and forms the naphthofuranone system in good yield. © 1998 Elsevier Science Ltd. All rights reserved.

The thermal rearrangement of 2-dienylcyclobutenones 1 to highly substituted annulated furans 3 was previously described (Scheme-1).¹ This transformation centered on the well precedented electrocyclic ring opening of the cyclobutenones to dienylketene intermediates 2 followed by their 6π electrocyclization and subsequent addition/elimination of the resulting phenol to the enol ether linkage.² We now report a complementary ring expansion of representative members of a 3-dienylcyclobutenedione series, *i.e.*, 3-(2-ethenylphenyl)cyclobutenediones 4 to naphtho[2,1-b]furan-2(3H)-ones 5.



0040-4039/98/\$19.00 © 1998 Elsevier Science Ltd. All rights reserved. PII: S0040-4039(98)00638-8 Thermolysis of 4a-d (*p*-xylenes, 138°C) gave naphthofuranones 5a-d in yields ranging from 47-76%. The rearrangement is envisaged to arise *via* a mechanism involving initial electrocyclic ring opening of the cyclobutenediones to the corresponding bisketenes 6 which then undergo a 6π electrocyclization followed by aromatization to the naphthols 7. Finally, addition of the naphtholic hydroxyl group to the remaining ketene gives the observed products 5a-d. Interestingly, thermolysis of 4b gave 2-(2ethylphenyl)-3-(1-butenyl)cyclobutene-1,2-dione (9) (26%) in addition to the benzofuranone 5d (47%) (Scheme-2). This unusual transformation is envisaged to arise from an initial 1,7-hydrogen shift to give the quinodimethane intermediate 8 followed by rearomatization *via* an analogous 1,7-shift to produce the observed product 9.³





Thermolysis of **4e** was studied as a possible new route to binaphthols, but, unfortunately, no isolable product was obtained. In comparison, the ketal precursor to **4e**, i.e., 2,3-di-(2-ethenylphenyl)-4,4-dimethoxycyclobutenone (**10e**) undergoes a most unusual thermal rearrangement (p-xylene, 138°C). Specifically, the polycyclic compound **13** was isolated in 72% yield (Scheme-3). As in the previous examples, the vinylketene intermediate **11** is envisaged to undergo electrocyclization to give the naphthol tautomer **12**. However, rather than tautomeric aromatization this quinodimethane is trapped by an intramolecular Diels-Alder cyclization to give **13**. The structure and stereochemistry of this product was established by X-ray crystallographic analysis.⁴



Synthesis of the requisite 3-(2-ethenylphenyl)cyclobutenediones was accomplished by employing the key synthetic intermediate, 2-(2-ethenylphenyl)-3,4,4-trimethoxycyclobutenone (15), which was prepared by a modification of a previously described general method for the regiospecific synthesis of cyclobutenones starting with dimethyl squarate (14) (Scheme-4).⁵ Specifically, treatment of 14 with 2-lithio-1-ethenylbenzene followed by trifluoroacetic anhydride (TFAA) and then methanol gave cyclobutenone 15 in 86% yield.⁶ 1,2 Addition of methyl- and *n*-butyllithium to 15 followed by hydrolysis (TFAA, H₂O) gave 10a (80%) and 10b (83%), respectively. Interestingly, treatment of 15 with the softer aryllithium reagents gave only 1,4 addition-elimination products. In this manner, the methoxy group at position-3 was directly replaced upon treatment with the respective aryllithium reagents to give 10c (95%), 10d (90%), and 10e (92%). Hydrolysis of ketals 10a-e gave 3-(2-ethenylphenylcyclobutene-1,2-diones 4a-e in excellent yields (87-99%).⁷



In conclusion the results presented here add to a growing but still limited data base concerning the chemistry of 1,2-bisketenes. The majority of the work concerning this class of reactive intermediates has focused primarily on their generation, stability, reactivity with nucleophiles and intermolecular cyclizations.⁸ The work outlined herein represents a new aspect of their chemistry and has direct analogies in the synthetically important ring expansion reactions of cyclobutenones.² Finally, it is noted that benzofuranones are found in a number of natural products and synthetic bio-active compounds.⁹ The fact that the starting cyclobutenediones are readily prepared from squaric acid and various organometallic reagents speaks to a potentially general route to this class of compounds.

Acknowledgment. The authors thank the National Institutes of Health (GM-36312) for financial support of this work and SmithKline Beecham for a generous gift of squaric acid.



Figure 1. ORTEP Drawing of Compound 13

References and Notes

- 1. Turnbull, P.; Heileman, M. J.; Moore, H. W. J. Org. Chem. 1996, 61, 2584.
- 2. For a recent review on the ring expansion of cyclobutenones see: Moore, H. W.; Yerxa B. R. Adv. Strain Org. Chem. 1995, 4, 81-162.
- For analogies for these 1,7-shifts see: (a) Marvell, E. N.; Caple, G.; Schatz, B.; and Pippin, W. *Tetrahedron* 1973, 29, 3781-3789. (b) Marvell, E. N.; Caple, G.; Delphey, C.; Platt, J.; Polston, N.; and Tashiro, J. *Tetrahedron* 1973, 29, 3806. (c) Baldwin, J. E.; and Reddy, V. P. J. Org. Chem. 1988, 53, 1129.
- 4. The structure assignments of the new compounds reported here are in strict agreement with their spectral and analytical data.
- 5. Gayo, L.; Moore, H. W. J. Org. Chem. 1992, 57, 6896.
- 6. 2-Lithio-1-ethenylbenzene was prepared by treating 2-bromostyrene with *n*-butyllithium.
- Another route to differentially substituted cyclobutenediones exists, but was ineffective when both subtituents were unsaturated. Liebeskind, L. S.; Fengl, R. W.; Wirtz, K. R.; and Shawe, T. T. J. Org. Chem. 1988, 53, 2482.
- For an excellent discussion of ketenes including bisketenes see (a) Tidwell, T. T. *Ketenes*; Wiley: New York, NY, 1995; (b) Allen, A. D.; Ronghua, L.; Ma, Jihai, McAllister, M. A., Tidwell, T. T.; and Zhao, Da. *Pure & Appl. Chem.* 1995, 67, 777-782; (c) Egle, I.; Lai, W.-Y.; Moore, P. A.; Renton, P.; Tidwell, T. T.; and Zhao, D. *J. Org. Chem.* 1997, 62, 18-25.
- (a) Anacardio, R.; Arcadi, A.; D'Anniballe, G.; Marinelli, F. Synthesis 1995, 831 and references therein.
 (b) Ramachandran, P.V.; Chen, G.-M.; Brown, H. C. Tetrahedron Lett. 1996, 37, 2205 and references therein.
 (c) Satoh, T.; Tsuda, T.; Kushino, Y.; Miura, M.; and Masakatsu, N. J. Org. Chem. 1996, 61, 6476-6477.