



**Novel Alkylaluminium Chloride Promoted [2+2] Cycloaddition
Reactions of Styrenes with 1,4-Naphthoquinones and Bromoquinones:
A Facile Route to Orthoquinodimethane Precursors**

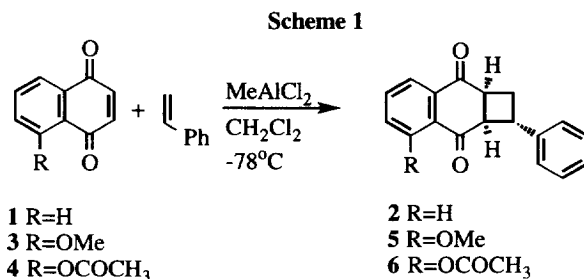
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Abstract: The first examples of a Lewis acid catalysed [2+2]cycloaddition between styrenes and naphthoquinones have been observed. The reactions of both methoxyl and acetoxylnaphthoquinones were both regio- and stereospecific. When *m*-methoxystyrene was employed a novel tetracycle was also formed, and by an unexpected mechanistic pathway. Extension to bromoquinones resulted ultimately in the formation of arylnaphthocyclobutenes, common precursors of the orthoquinodimethanes.

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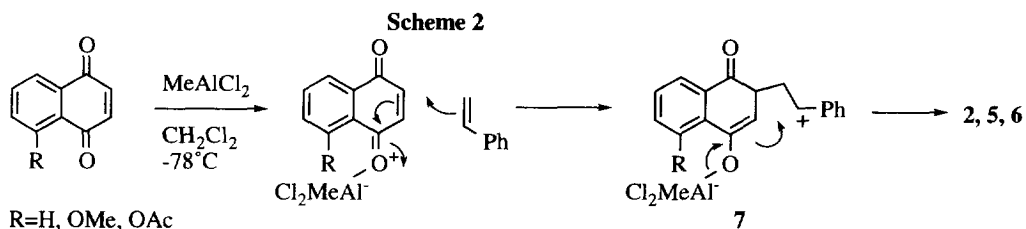
We have recently reported the dimethylaluminium chloride promoted stereospecific [2+2] cycloaddition of dihydrofuran with 1,4-benzo- and naphthoquinones.¹ Indeed Lewis acid promoted [2+2] cycloadditions of unactivated alkenes to enones has been an area of hectic activity, according to the recent literature.^{2a-c} In particular, Engler and co-workers have shown that Ti(IV) promotes [2+2] cycloadditions between propenyl benzenes and 1,4-benzoquinones.^{3a,b}



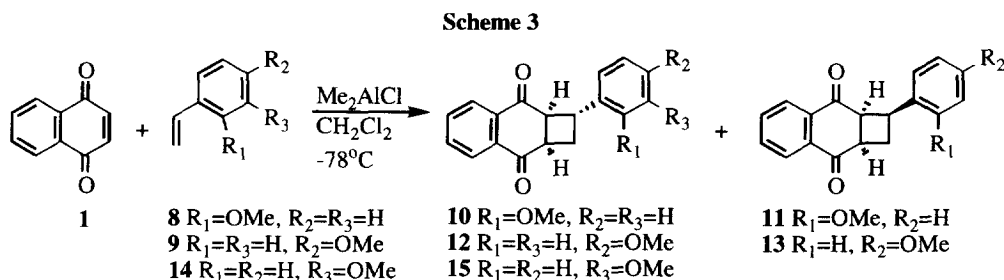
In the course of an investigation into a possible Lewis acid catalysed [4+2] cycloaddition of styrene with 1,4-naphthoquinone **1**, we unexpectedly isolated the cyclobutane **2** when MeAlCl₂ was employed as the promoter. This is the first recorded example of a Lewis acid promoted [2+2] cycloaddition of styrene to the naphthoquinone **1**.^{4,5} Furthermore, the unsymmetrical quinones **3** and **4**, afforded regio- and stereospecifically

the cyclobutanes **5** and **6**, Scheme 1, also in good yield. None of the naphthofurans potentially derivable from the cyclobutane products were detected.^{3,6} We therefore initiated a study of this novel reaction.

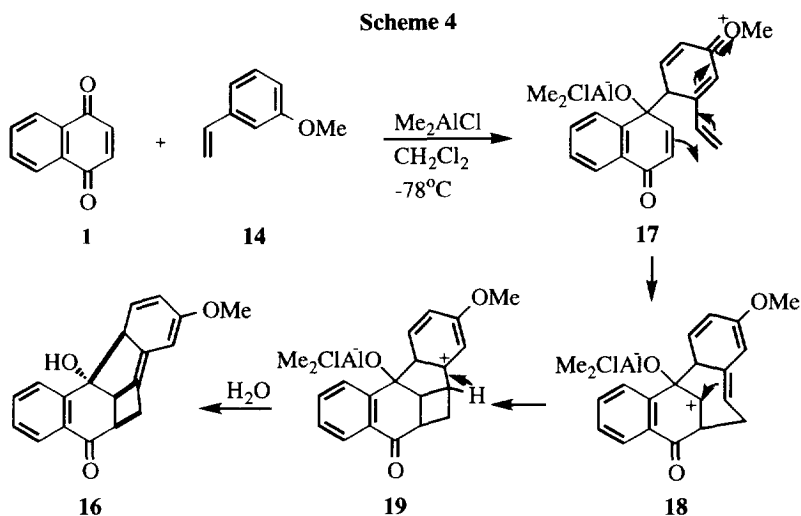
The mechanisms employed by other investigators in this general area have been extended to explain the formation of these products.^{2a,f} Thus, it is proposed that [2+2] cycloaddition occurs by initial Lewis acid coordination to the quinone, subsequent Michael addition of styrene, followed by rapid ring closure of the intermediate dipolar ion **7**, Scheme 2, affording stereospecifically,⁷ the cyclobutane with *exo* stereochemistry. The cyclobutanes **5** and **6** are formed regioselectively, probably as a result of bidentate coordination of the Lewis acid at the C-4 carbonyl oxygen and the C-5 oxygen substituent.



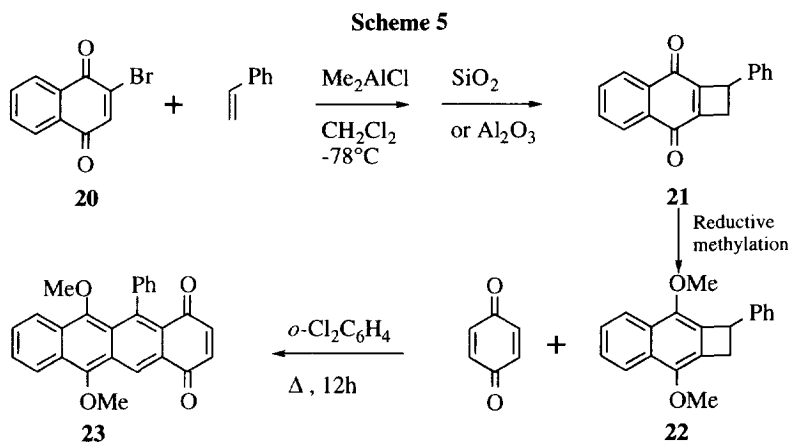
Extension of this reaction with quinone **1** to the activated styrenes, *o*- and *p*-methoxystyrene, **8** and **9**, afforded in both cases an approximately 3:2 mixture of diastereomers **10,11** and **12,13**, respectively, upon quenching the reaction after 30 minutes. Interestingly, treatment of the separated cyclobutane epimers **10** and **11**, with two equivalents of Me₂AlCl at -78°C, resulted in complete conversion of the *endo* adduct **11** to the *exo* adduct **10**, within one hour. Under the same conditions the *exo* adduct **10** remained unchanged.



The use of *m*-methoxystyrene **14** in the reaction with quinone **1** afforded the *exo* [2+2] adduct **15** and the transannulated tetracycle **16**.⁸ None of an *endo* adduct, the epimer of **15**, was detected. We initially assumed that **16** had been formed *via* the *endo* [2+2] adduct by a Lewis acid catalysed transannular nucleophilic attack by the pendant aryl group on the neighbouring carbonyl group. Fortunately, we were enabled to test this mechanistic proposal. When 2-methylbenzoquinone was treated under the usual conditions with *m*-methoxystyrene, both the *endo* and *exo* [2+2] cycloadducts, together with the tetracycle corresponding to **16**, were formed. When the pure *endo* [2+2] adduct was treated with Me₂AlCl conversion to the *exo* [2+2] adduct only was observed. None of the tetracycle was detected. To explain the formation of **16**, we now propose initial 1,2 addition to the carbonyl⁹ with formation of the intermediate **17**. Subsequent sequential intramolecular [2+2] cycladdition ultimately results in the formation of the tetracycle **16**, Scheme 4.



Interestingly, extension of the reaction to bromoquinones, such as **20**, resulted in the formation of the cyclobutene **21**, following facile dehydrobromination of the labile bromoadduct with either silica or alumina. Subsequent reductive methylation¹⁰ afforded the naphthocyclobutene **22**, in good overall yield. This methodology represents a facile approach to these valuable *o*-quinodimethane precursors which are otherwise difficultly accessed.¹¹ The cyclobutene **22** was thermally ring opened and trapped with benzoquinone and after exposure to air, yielded the [4+2] cycloadduct **23**.



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REFERENCES AND NOTES

- Neville, D.; Murphy, W.S. *Tetrahedron Lett.* **1996**, 37, 5221-5224.
- (a) Yamazaki, S.; Fujitsuka, H.; Takara, F.; Inoue, T. *J. Chem. Soc. Perkin Trans. 1* **1994**, 695-700. (b) Hojo, M.; Tomita, K.; Hirohara, Y.; Hosomi, A. *Tetrahedron Lett.* **1993**, 34, 8123-8126. (c) Narasaka, K.; Hayashi, Y.; Shimadzu, H.; Niihata, S. *J. Am. Chem. Soc.* **1992**, 114, 8869-8885. (d) Ahmed, S. *Tetrahedron Lett.* **1991**, 32, 6997-7000. (e) Quendo, A.; Rousseau, G. *Tetrahedron Lett.* **1988**, 29, 6443-6446. (f) Brengel, G.P.; Rithner, C.; Meyers, A.I. *J. Org. Chem.* **1994**, 59, 5144-5146.
- (a) Engler, T.A. *Stud Nat. Prod. Chem.* **1995**, 16, 547-569. (b) Engler, T.A.; Combrink, K.D.; Letavic, M.A.; Lynch, K.O.; Ray, J.E. *J. Org. Chem.* **1994**, 59, 6567-6587.
- The chemistry is related to that described by Engler,^{3a,b} however attempts to employ TiCl₄ as promoter in the reactions with 1,4-naphthoquinones gave no isolable product. Our chemistry was equally applicable to 1,4-benzoquinones. For examples of photochemical [2+2] cycloadditions of 1,4-naphthoquinone with styrene see: (a) Krauch, C.H.; Farid, S. *Tetrahedron Lett.* **1966**, 4783. (b) Maruyama, K.; Otsuki, T.; Takuwa, A.; Kako, S. *Bull. Inst. Chem. Res., Kyoto Univ.* **1972**, 50, 344.
- All new compounds gave satisfactory spectroscopic and analytical data.
- Banville, J.; Brassard, P. *J. Chem. Soc., Perkin Trans. 1*, **1976**, 613.
- We believe that the (5+2)[4π+2π] cycloaddition mechanism proposed by Engler^{3a,b} does not occur in these reactions since such a mechanism would result in loss of aromaticity of the aryl ring in quinone **1**. No products derived from such intermediates were detected.
- m.p.200-200°C; ν_{\max} (KBr), 3426 (br), 1648 (s), 1474 (w) and 1110 (w) cm⁻¹; δ_{H} (270 MHz) 8.02 (1H, dd, *J* 8.40, 1.35 Hz, *ArH*), 7.84 (1H, dd, *J* 8.40, 1.35 Hz, *ArH*), 7.63 (1H, ddd, *J* 8.40, 8.40, 1.35 Hz, *ArH*), 7.46 (1H, ddd, *J* 8.40, 8.40, 1.35 Hz, *ArH*), 7.25 (1H, d, *J* 7.31 Hz), 7.00 (1H, d, *J* 1.96 Hz), 6.77 (1H, dd, *J* 7.31, 1.96 Hz), 3.83 (3H, s, OCH₃), 3.55 (1H, s), 3.24 (1H, d, *J* 4.82 Hz), 2.70 (1H, ddd, *J* 8.68, 1.93, Hz), 2.41 (1H, brs, D₂O exchangeable), 2.00 (1H, ddd, *J* 13.50, 4.82, 1.93 Hz) and 1.68 (1Hdd, *J* 13.50, 8.68 Hz); δ_{C} (67.80 MHz) 200.50(C), 159.51(C), 148.23(C), 143.64(C), 134.20(CH), 132.60(C), 130.17(C), 127.96(CH), 126.48(CH), 126.43(CH), 124.60(CH), 111.81(CH), 109.82(CH), 91.60(C), 60.32(CH), 55.50(CH₃), 52.62(CH), 49.91(CH) and 32.90(CH₂); LREIMS 292 (M⁺, 57%), 172(100) and 158(44).
- For a related intramolecular 1,2-nucleophilic addition of a dienone see: Majetich, G.; Khetani, V. *Tetrahedron Lett.* **1990**, 31, 2243-2246.
- Kraus, G.A.; On Man, T. *Synth. Commun.* **1986**, 16, 1037-1042.
- Charlton, J.L.; Alauddin, M.M. *Tetrahedron* **1987**, 43, 2873-2889.

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