difficulties. To the contrary, it has been our experience over the last 6 years that these molecules can be readily synthesized and are easy to handle. And with the generality of the quinone synthesis described herein, it is anticipated that newer, even simpler methods of cyclobutenedione synthesis will be explored in the near future. By combining the chemistry described in this manuscript with the numerous procedures known for directed metalation of aryl and heterocyclic systems,[15] a powerful procedure is at hand for the synthesis of quinone based biologically active molecules.

Acknowledgment. This investigation was supported by PHS Grant CA 40157 awarded by the National Cancer Institute, DHHS. We are grateful to Professor Harold Moore of U.C. Irvine for communicating his results to us prior to publication and to Dr. Romanworq Ferede and Mr. Charles McSwain for their efforts on the project.

Supplementary Material Available: Complete experimental details for the synthesis of the compounds described in this manuscript (13 pages). Ordering information is given on any current masthead page.

(15) Beak, P.; Snieckus, V. *Acc. Chem. Res.* **1982**, *15*, 306. For the two most recent articles in this area see: Shankaran, K.; Soan, C. P.; Snieckus, V. *Tetrahedron Lett.* **1985**, *26*, 5997 and Sibi, M. P.; Chattopadhyay, S.; Dankwardt, J. W.; Snieckus, V. *J. Am. Chem. Soc.* **1985**, *107*, 6312.

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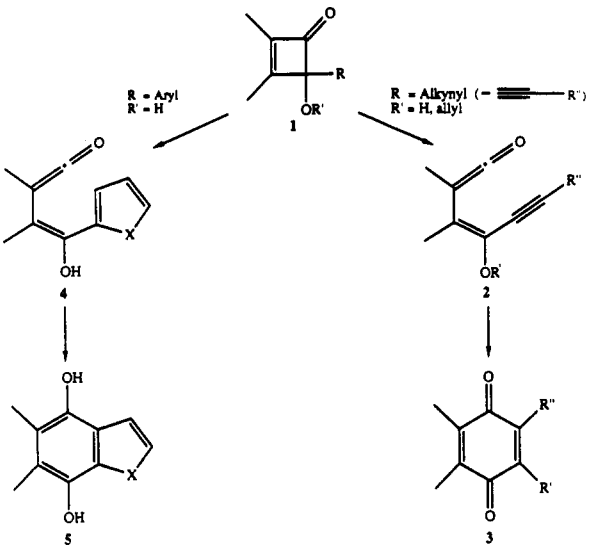
Synthesis of Benzoquinones and Annulated Derivatives from Conjugated Ketenes

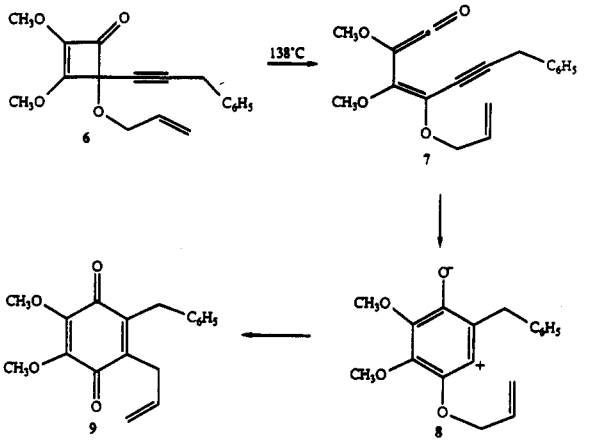
Summary: A new convergent general synthesis of annelated quinones and highly substituted benzoquinones from in situ generated conjugated ketenes is presented.

Sir: Reported here are two related general synthetic routes to highly substituted benzoquinones and annulated derivatives (Scheme I). First, 4-alkynyl-4-hydroxy- and 4-alkynyl-4-(allyloxy)cyclobutenones **1** (R = alkynyl) were found to undergo an interesting rearrangement (138 °C, *p*-xylene) to the quinones **3** in which R′ is a proton or an allyl group, respectively.[1] Second, 4-aryl-4-hydroxycyclobutenones **1** (R = aryl) were found to rearrange to the hydroquinones **5** (X = S, O, —CH=CH—) when subjected to the same conditions.[2,3] These transformations are

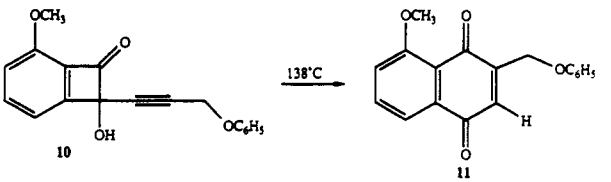
Scheme I



Scheme II



Scheme III



suggested to be dictated by a favored conrotatory ring opening of the cyclobutenones **1** such that the electron-donating substituents (OR′) rotate outward.[4] Thus, the configuration of the resulting ketenes **2** and **4** is such that their electrophilic site can directly interact with the proximal alkyne or aryl group.

A particularly interesting example is that involving the allyl group migration (Scheme II). Here, the starting cyclobutenone **6** was prepared from 2,3-dimethoxycyclobutenedione via initial alkynylation ($LiC{\equiv}CCH_2C_6H_5$, THF, −78 °C; 5% NH_4Cl; 65%) followed by allylation of the resulting alcohol ($ICH_2CH{=}CH_2$, Ag_2O, K_2CO_3, dioxane, 25 °C; 74%).[5] Thermolysis of **6** for 1 h in refluxing *p*-xylene gave the benzoquinone **9** (76%). This rear-

(1) In a related report, 4-alkynyl-4-(trimethylsiloxy)cyclobutenones were shown to rearrange to trimethylsilyl-substituted benzoquinones. See: Karlsson, J. O.; Nguyen, N. V.; Foland, L. D.; Moore, H. W. *J. Am. Chem. Soc.* **1985**, *107*, 3392.

(2) This reaction has been independently discovered. See: Liebeskind, L. S.; Iyer, S.; Jewell, C. F. Jr. *J. Org. Chem.*, previous communication in this issue.

(3) This is analogous to the ring expansion of other 4-arylcyclobutenones lacking the 4-OR group to phenols. See: Smith, L. I.; Hoehn, H. H. *J. Am. Chem. Soc.* **1939**, *61*, 2619. Smith, L. I.; Hoehn, H. H. *Ibid.* **1941**, *63*, 1181. Nieuwenhuis, J.; Arens, J. F. *Rec. Trav. Chim. Pays-Bas* **1958**, *77*, 1153. Wittmann, H.; Illi, V.; Sterk, H.; Ziegler, E. *Monatsh. Chem.* **1968**, *99*, 1982. Zubovics, Z.; Wittmann, H. *Liebigs Ann. Chem.* **1972**, *765*, 15. Kipping, C.; Schiefer, H.; Schonfelder, K. *J. Prakt. Chem.* **1973**, *315*, 887. Neuse, E. W.; Green, B. R. *Liebigs Ann. Chem.* **1974**, *9*, 1534. Mayr, H. *Angew. Chem., Int. Ed. Engl.* **1975**, *14*, 500. Huisgen, R.; Mayr, H. *J. Chem. Soc., Chem. Commun.* **1976**, 55. Huisgen, R.; Mayr, H. *Ibid.* **1976**, 57. Danheiser, R. L.; Gee, S. K. *J. Org. Chem.* **1984**, *49*, 1674.

(4) A theoretical evaluation of this conrotatory mode which is in agreement with this prediction has been reported for the electrocyclic ring openings of cyclobutenes. See: Houk, K. N.; Randan, N. G. *J. Am. Chem. Soc.* **1985**, *107*, 2099. For an experimental analogy in the cyclobutenone series, see: Baldwin, J. E.; McDaniel, M. C. *Ibid.* **1968**, *90*, 611.

(5) All new compounds gave satisfactory C,H analyses or high resolution mass spectroscopy data. Their assigned structures are consistent with spectral data.

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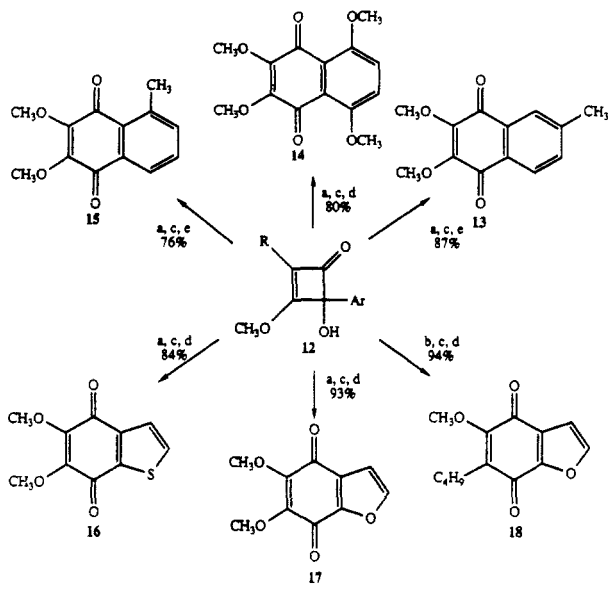
Scheme IV[a]



[a] (a) R = CH_3O; (b) R = n-C_4H_9; (c) 138 °C, p-xylene; (d) Ag_2O, K_2CO_3, C_6H_6, 1 h; (e) Ce(IV)/SiO_2, CH_2Cl_2, 10 min.

rangement is envisaged to involve the (2-alkynylethenyl)ketene **7** which cyclizes to the zwitterionic species **8**. Subsequent intramolecular electrophilic attack on the allyl double bond and C–O bond cleavage leads to **9**.

The cyclobutenol precursor to **6** was also subjected to thermolysis at 138 °C for 1 h. This gave a 71% isolated yield of 2-benzyl-5,6-dimethoxy-1,4-benzoquinone.[6] Still another example of this reaction mode is given in Scheme III. This case not only illustrates the unusual hydrogen migration but also presents a potentially general regiospecific route to naphthoquinones. Here, the benzocyclobutenone **10**, obtained in 75% yield upon alkynylation of the corresponding methoxybenzocyclobutenedione, gave **11** in 84% yield when subjected to thermolysis.[7]

Finally, we report that 4-aryl-4-hydroxycyclobutenones **12** undergo facile rearrangement to the corresponding hydroquinones in refluxing p-xylene after 2 h.[8,9] These were oxidized (Ag_2O or Ce(IV)/SiO_2)[10] to the respective quinones **13**–**18** which were isolated in 76–93% overall yields (Scheme IV). Particular note is made of the **12** to **18** transformation since this was accomplished with complete regiocontrol starting from 3-butyl-4-methoxycyclobutenedione and 3-lithiofuran.[11,12] The starting cyclobutenones were prepared in 59–73% isolated yields by treating the cyclobutenediones (THF, −78 °C) with the appropriate aryllithium reagent and quenching the reaction with 5% NH_4Cl at −78 °C.

The results presented here represent very general and efficient synthetic routes to highly functionalized quinones and hydroquinones. Further details will be reported subsequently.

Acknowledgment. We thank the National Institutes of Health (CA-11890, AI-15651) and the National Science Foundation (CHE-80-25567) for financial support of this work.

Registry No. **6**, 102683-41-0; **9**, 102683-43-2; **10** (isomer 1), 102683-45-4; **10** (isomer 2), 102696-56-0; **10** (dione), 62416-22-2; **11**, 102683-46-5; **12** (R = OCH_3, Ar = H), 102683-47-6; **12** (R = C_4H_9, Ar = H), 102683-48-7; **13**, 102632-08-6; **14**, 51783-58-5; **15**, 102632-07-5; **16**, 102683-49-8; **17**, 102683-50-1; **18** (isomer 1), 102683-51-2; **18** (isomer 2), 102683-53-4; $C_6H_5CH_2C{\equiv}CLi$, 102683-42-1; $ICH_2CH{=}CH_2$, 556-56-9; 2,3-dimethoxycyclobutenedione, 5222-73-1; 2-benzyl-5,6-dimethoxy-1,4-benzoquinone, 102683-44-3; 3-butyl-4-methoxycyclobutenedione, 102683-52-3; 3-lithiofuran, 53101-93-2; 2-lithiofuran, 2786-02-9.

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(6) We have documented 10 examples of this rearrangement.
(7) Alkynylation of the methoxybenzocyclobutenedione gave a 9:1 mixture of regioisomers. From electronic considerations, **10** is assumed to be the major regioisomer.
(8) In principle this is analogous to the metal-mediated synthesis of naphthols from alkynes and chromium carbene complexes. See, for example: Dotz, K-H.; Pruskil, I.; Muhlemeir, V. *Chem. Ber.* **1982**, *115*, 1278. Semmelhack, M. F. "Regioselectivity in Metal Promoted Carbon–Carbon Coupling Reactions" in *Selectivity–A Goal for Synthetic Efficiency*; Bartmann, W., Trost, B. M. Eds., Verlag Chemie: Weinheim, 1984.
(9) It is necessary to protonate the initially formed alkoxide at −78 °C. If not, other chemistry dominates. For analogies see: Swenton, J. S.; Jackson, D. K.; Manning, M. J.; Raynolds, P. W. *J. Am. Chem. Soc.* **1978**, *100*, 6182. Spangler, L. A.; Swenton, J. S. *J. Org. Chem.* **1984**, *49*, 1801.
(10) Fisher, A.; Henderson, J. *Synthesis* **1985**, 641.
(11) 3-Butyl-4-methoxycyclobutenedione was prepared in 47% yield by treating 2,3-dimethoxycyclobutenedione with butyllithium followed by mild acid hydrolysis. On the basis of previous analogy (ref 9, for example) as well as upon NMR arguements, the regiochemistry of the cyclobutenol obtained upon arylation of the above dione is assigned as shown.
(12) The regioisomer of **18** was obtained in 91% when 2-lithiofuran was employed.

The Structure and Kinetic Reactivity of a Pyrrolidine-Derived Vinylogous Urethane Lithium Enolate

Summary: NMR data show the enolate **1** possesses a highly twisted diene skeleton. This enolate undergoes kinetic and anti selective aldol reactions at its distal C-4 position.

Sir: We have described some novel anti selective aldol reactions of the lithium enolate **1**.[1] To more thoroughly control this enolate, an examination of both its structure and its mode of reaction with aldehydes was undertaken. Data which delineate both an unusual structure for **1** and establish the kinetic nature of its aldol reactivity are detailed below.

The E configuration of substituents [$(CH_2)_4N$ and CO_2CH_3] for substances like **2** is known to be thermodynamically favored.[2] An s-cis orientation of olefin and carbonyl residues predominated in **2** as evidenced by a 20% NOE found between the methoxy group of the ester and the C-2 vinyl proton.[3] ^1H NMR studies of **2** indicate a C-1–C-2 bond rotation of 7.4 kcal/mol (T_c = 154 K, THF-d_8) and 13.4 kcal/mol (T_c = 286 K, THF-d_8) for the degenerate rotation of the pyrrolidine ring.[4]

Deprotonation of **2** with LDA (THF/−78 °C) followed by reaction with Me_3SiCl gave a single distillable (0 °C, 10^{-6} torr) ketene acetal enamine, **3** (Scheme I). Desilylation of **3** with CH_3Li (THF/−78 °C) gave enolate **1**.[5] Z

(1) Schlessinger, R. H.; Bebernitz, G. R.; Lin, P.; Poss, A. J. *J. Am. Chem. Soc.* **1985**, *107*, 1777–1778 and references cited therein.
(2) Smith, D. *Spectrochim. Acta Part A* **1976**, *32A*, 1477–1488, 1489–1502.
(3) Infrared studies verify this conclusion, see ref 2.
(4) Dabrowski, J.; Kozerski, L. *Org. Magn. Reson.* **1973**, *5*, 469–470.

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