demonstrated by metalation of **4** and addition of 1-bromo-4-chlorobutane which led to **8** and the latter was transformed into **9** in a single step upon warming with the hydrazine solution. Removal of the methoxymethyl group (Table I) gave **10**. In a third approach to indole alkaloids, the yohimbane skeleton was efficiently reached by metalation of **4** followed by addition of the ethyl benzoate derivative,[9] furnishing **11**. When **11** was warmed with the hydrazine reagent, the lactam **12** was formed directly (Table I). As before, the methoxymethyl group was removed without event, affording **13**.

In summary, the α-amino carbanions derived from tetrahydro-β-carbolines are now accessible and were found to be suitable precursors to a variety of indole alkaloidal systems. Further studies directed toward specific target molecules are in progress.

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Registry No. **1**, 81535-31-1; **2**, 81535-32-2; **3**, 81535-33-3; **4**, 81535-34-4; **5a**, 81535-35-5; **5b**, 81535-36-6; **5c** (isomer 1), 81535-37-7; **5c** (isomer 2), 81535-38-8; **6a**, 81535-39-9; **6a** (R = CH_2OH), 32703-22-3; **6b**, 81535-40-2; **6b** (R = CH_2OH), 81535-41-3; **7a**, 2506-10-7; **7b**·HCl, 6650-05-1; **8**, 81535-42-4; **9**, 81535-43-5; **9** (R = CH_2OH), 81535-44-6; **10**, 4802-79-3; **11**, 81535-45-7; **12**, 81535-46-8; **12** (R = CH_2OH), 81535-47-9; **13**, 81535-48-0; tetrahydro-β-carboline, 16502-01-5; methyl iodide, 74-88-4; isobutyl iodide, 513-38-2; benzaldehyde, 100-52-7; 1-bromo-4-chlorobutane, 6940-78-9; ethyl 2,3-dimethoxy-6-(chloromethyl)benzoate, 65495-31-0.

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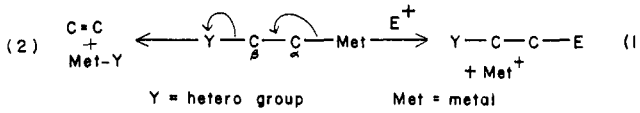
Reductive Cyclization of Mercurial Enones

Summary: A series of enones containing pendant isolated olefinic linkages was prepared. Solvomercuration could be conducted specifically at the isolated double bond. Treatment of these systems with sodium trimethoxyborohydride results in reductive cyclization.

Sir: Organometallic systems that bear hetero substituents at the β-carbon and that are attacked by a range of electrophiles (E^+) are potentially useful implements in synthesis. Equations 1 and 2 implicitly express both the opportunities and stability problems inherent in such structures.[1-3]

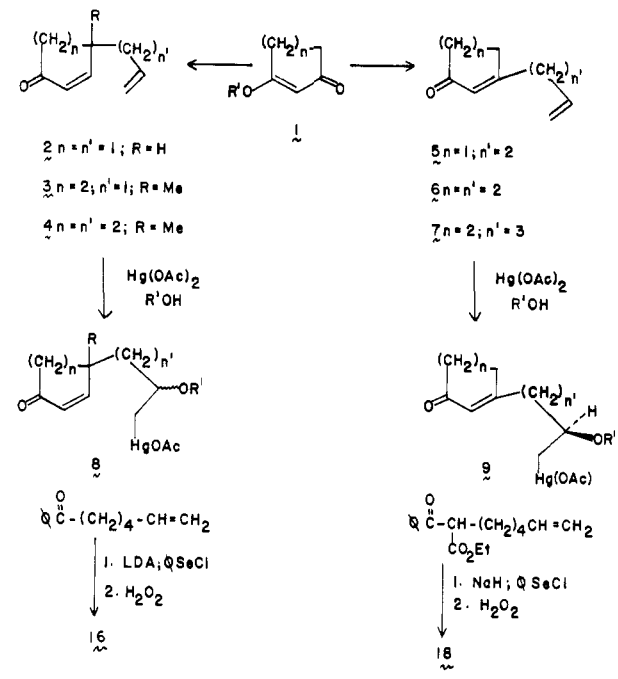


(1) For early attempts to prepare such systems, see: (a) Normant, H. *Bull. Soc. Chim. Fr.* **1972**, 2161. (b) Steinborn, D. *J. Organomet. Chem.* **1979**, *182*, 313. (c) Schlosser, M.; Ladenberger, V. *Angew. Chem., Int. Ed. Engl.* **1966**, *5*, 519.

(2) For recent reports on successful generation of such systems, see: Barluenga, J.; Fananas, F. J.; Yus, M. *J. Org. Chem.* **1981**, *46*, 1281 and ref 13 and 14 therein.

(3) For some recent examples of vinyllithium reagents bearing β-hetero substituents, see: (a) Ficini, J.; Falou, S.; Touzin, A. M.; d'Angelo, J. *Tetrahedron Lett.* **1977**, 3589. (b) Wollenberg, R. H.; Ablizati, K. F.; Peries, R. *J. Am. Chem. Soc.* **1977**, *99*, 7365. (c) Lau, K. S. Y.; Schlosser, M. *J. Org. Chem.* **1978**, *43*, 1595. (d) Skold, C. N. *Synth. Commun.* **1976**, *6* (2), 119. (e) Vlattas, I.; Vecchia, L. D.; Lee, A. O. *J. Am. Chem. Soc.* **1976**, *98*, 2008.

Scheme I



Mercurials bearing β-hetero substitution are readily available through the solvomercuration of olefins.[4-8] Unfortunately, the carbon–mercury bond is insufficiently nucleophilic to participate in many reactions such as are implied in eq 1.[5-8] Indeed, the viability of such compounds is probably not unrelated to the covalent character of the carbon–mercury bond.

We were, therefore, struck by some findings of Giese[9-11] (eq 3) to the effect that several β-methoxy mercurials undergo "reductive" coupling with electrophilic olefins upon treatment with sodium trimethoxyborohydride. Though proceeding presumably through a free-radical pathway,[12-14] the Giese reaction corresponds, in its overall synthetic consequence, to eq 1.

We have begun to study the synthetic potentialities[15,16] implicit in the reductive coupling of mercurials. For instance, it was of interest to learn whether the process would be operative with electrophilic substrates that are more

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(5) Staul, H.; Zeller, K. P.; Leditsche, H. *Methoden Org. Chem. (Houben-Weyl), 4th Ed.* **1974**, 13/2b, 130–152.

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(8) Negishi, E. I. "Organometallics in Organic Synthesis"; Wiley: New York, **1980**; pp 455–479.

(9) Giese, B.; Heuck, K. *Chem. Ber.* **1979**, *112*, 3759.

(10) Giese, B.; Heuck, K. *Tetrahedron Lett.* **1980**, *21*, 1829.

(11) (a) Giese, B.; Heuck, K. *Chem. Ber.* **1981**, *114*, 1572. (b) In a paper that appeared since submission of our manuscript, Giese has extended his intermolecular reaction to include α,β-unsaturated ketones. (See: Giese, B.; Horler, H.; Zwick, W. *Tetrahedron Lett.* **1982**, 531.)

(12) Giese, B.; Meister, J. *Chem. Ber.* **1977**, *110*, 2588.

(13) Hill, C. L.; Whitesides, G. M. *J. Am. Chem. Soc.* **1974**, *96*, 870.

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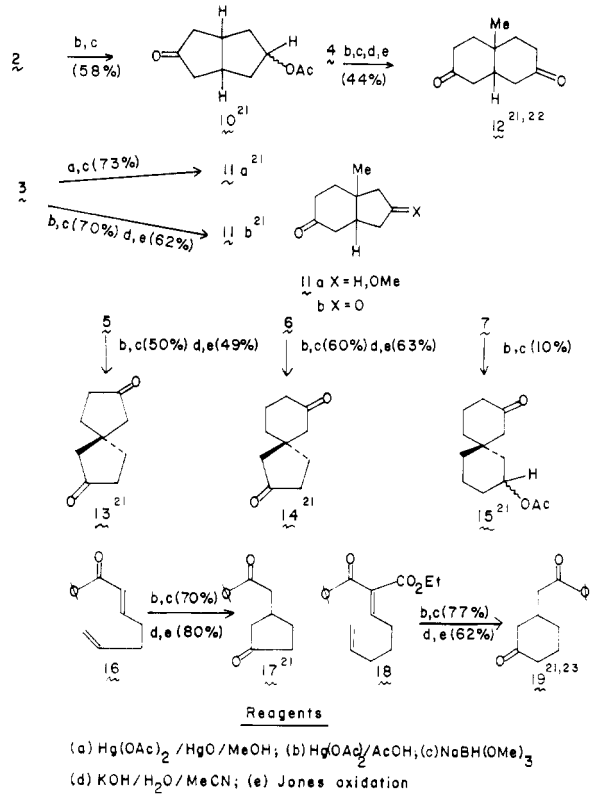
(15) Similar objectives have been accomplished by cyclization of a protonated enone to a proximal double bond or aromatic ring with attack by a nucleophile. For example, see: (a) Naegeli, P. *Tetrahedron Lett.* **1978**, 2127 and references therein. (b) Harding, K. E.; Cooper, J. L.; Puckett, P. M. *J. Am. Chem. Soc.* **1978**, *100*, 993. (c) Davis, B. R.; Johnson, S. J. *J. Chem. Soc., Chem. Commun.* **1978**, 614.

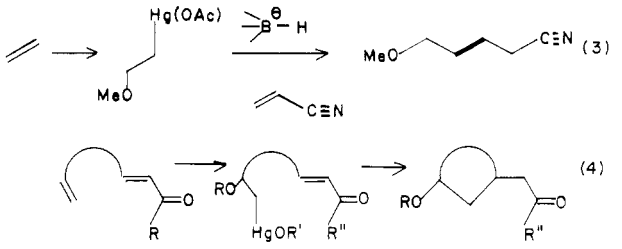
(16) Related cyclizations of alkyl tin(iv) compounds have been described by Macdonald. It will be noted that our method proceeds from an olefinic precursor and allows for the introduction of a β-hetero substituent. Macdonald, T. L.; Mahalingam, L. *J. Am. Chem. Soc.* **1980**, *102*, 2113.

0022-3263/82/1947-2231$01.25/0

Scheme II



susceptible to direct reduction by borohydride species than the Giese substrates.[9-11a,b] Given the required relative susceptibilities to reduction, this methodology could be used in ring-building strategies. This communication sets fourth our first findings in this connection, wherein the formalism of eq 1 has been reduced to practice.



In all but one case,[17] the precursors (2–7) were obtained from the β-alkoxycyclenones 1 by conventional methods (Scheme I). Thus, alkylation of the derived α′-lithium enolate,[18] followed by reduction ($LiAlH_4$) and acidic hydrolysis, afforded the "pre-fused" systems 2 and 3. Alternatively, reaction of systems 1 with Grignard reagents, followed by acidic hydrolysis, gave the "pre-spiro" systems 5–7.[19] The acyclic substrates 16 and 18 (vide infra) were prepared by selenenylation–dehydroselenenylation[20] of dihydro precursors that were obtained by alkylation of the appropriate enolates with the ω-bromoalkenes.

In each case, solvomercuration (either methoxymercuration or acetoxymercuration) could be carried out selectively on the isolated double bond. For dienes 2–4, the resulting mercurial 8 is already a (1:1) mixture of diastereomers. Mercurial type 9, derived from precursors 5–7, must be a single diastereomer.

Solvomercuration was conducted either in methanol (condition a) or in acetic acid (condition b). From the standpoint of the quality of the mercuration–reductive cyclization sequence, the former was more efficient. However, for purposes of the eventual convergence of the diastereomers, acetoxymercuration was preferred. The best conditions we have thus far devised for reduction involve the use of sodium trimethoxyborohydride in methylene chloride.[10] The yields are shown for the conversion of olefin to the products of reductive cyclization. Where convergence to a single diketone was achieved, the yield of the convergence sequence is also provided.[21]

The most serious side reactions in the reductive cyclization step were (i) reduction without cyclization and (ii) reductive reversion to olefin. *In no case could we obtain products corresponding to reduction of the enone prior to reduction of the mercurial. It is clear that reduction of the β-hetero-substituted mercurials can be achieved in the face of otherwise readily reducible functionality.*

Already some potentially serious limitations begin to emerge. For instance, the reductive cyclization step is badly undermined where a quarternary carbon is being created as part of a six-membered ring (cf. conversion 7 → 15). In such a case, reduction and reductive elimination become the principal processes. Nonetheless, on the basis of these and other results in our laboratory, it seems likely that reductive cyclization of enones and other electrophilic olefins with pendant carbon mercury bonds may be a useful device in a variety of synthetic undertakings. Future research will be addressed to learning more about the applicability, limitations, and mechanism of this interesting process.

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Registry No. 2, 73127-99-8; 3, 13481-16-8; 4, 60729-42-2; 5, 79191-35-8; 6, 22627-45-8; 7, 70079-75-3; 10, 81555-39-7; 11a, 81555-40-0; 11b, 81571-99-5; 12, 5502-15-8; 13, 81555-41-1; 14, 81555-42-2; 15, 81555-43-3; 16, 81555-44-4; 17, 81555-45-5; 18, 81555-46-6; 19, 60565-09-5; 1-phenyl-6-hepten-1-one, 15177-05-6; ethyl 2-benzoyl-7-octenoate, 81555-47-7.

(17) Compound 4 was prepared by Robinson annulation of the piperidine enamine of 2-methyl-5-hexenal with methyl vinyl ketone (cf. Stork, G.; Dolfini, J. E. *J. Am. Chem. Soc.* **1963**, *85*, 2872).

(18) Cf. Stork, G.; Danheiser, R. L. *J. Org. Chem.* **1973**, *38*, 1775.

(19) Cf. Conia, J. M.; Beslin, P. *Bull. Soc. Chim. Fr.* **1969**, 483.

(20) Reich, H. J.; Renga, J. M.; Reich, I. L. *J. Am. Chem. Soc.* **1975**, *97*, 5434.

(21) The structures assigned to these compounds are in accordance with their spectral properties, which are given below. The ^1H NMR spectra were recorded on a Varian EM390 90-MHz system in $CDCl_3$ with Me_4Si as internal standard. **10**: ^1H NMR δ 1.6–3.0 (m, 20 H), 1.98 (s, 3 H), 2.03 (s, 3 H), 5.1–5.4 (m, 2 H); IR (CCl_4) 1745 cm^{-1}; MS, *m/e* 182.1 (M^+). **11a**: ^1H NMR δ 1.17 (s, 3 H), 1.27 (s, 3 H), 1.3–2.6 (m, 22 H), 3.27 (s, 6 H), 3.7–3.9 (m, 2 H); IR ($CHCl_3$) 1710 cm^{-1}; MS, *m/e* 182.1 (M^+). **11b**: ^1H NMR δ 1.38 (s, 3 H), 1.8–2.75 (m, 11 H); MS, *m/e* 166.2 (M^+). **12**: ^1H NMR δ 1.37 (s, 3 H), 1.5–2.9 (m, 13 H). **13**: ^1H NMR δ 1.7–2.5 (m, 6 H); IR ($CHCl_3$) 1740 cm^{-1}; MS, *m/e* 152.1 (M^+). **14**: ^1H NMR δ 1.6–2.4 (m, 14 H); IR ($CHCl_3$) 1740, 1715 cm^{-1}; MS, *m/e* 166.1 (M^+). **15**: ^1H NMR δ 1.0–2.0 (m, 12 H), 2.0 (s, 3 H), 2.1–2.4 (m, 4 H), 4.7–5.1 (m, 1 H); IR ($CHCl_3$) 1725, 1710 cm^{-1}. **17**: ^1H NMR δ 1.4–3.0 (m, 7 H), 3.1–3.2 (m, 2 H), 7.2–7.7 (m, 3 H), 7.8–8.1 (m, 2 H); IR ($CHCl_3$) 1740, 1680 cm^{-1}; MS, *m/e* 202.1 (M^+). **19**: ^1H NMR δ 1.2–2.8 (m, 9 H), 2.9–3.1 (m, 2 H), 7.3–7.7 (m, 3 H), 7.9–8.1 (m, 2 H); IR ($CHCl_3$) 1710, 1680 cm^{-1}; MS, *m/e* 216.2 (M^+).

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