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Electrochemical Generation and Reaction of *o*-Quinodimethanes from {[[2-(2,2-Dibutyl-2-stannahexyl)phenyl]-methyl]thio}benzenes

Madoka Jinno, Yoshikazu Kitano, Masahiro Tada, and Kazuhiro Chiba*

*Laboratory of Bio-organic Chemistry, Tokyo University of Agriculture and Technology,
3-5-8 Saiwai-cho, Fuchu, Tokyo 183-8509, Japan*

chiba@cc.tuat.ac.jp

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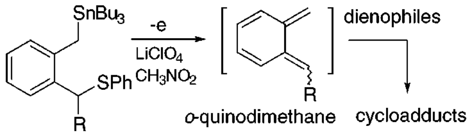
ABSTRACT



The anodic oxidation of {[[2-(2,2-dibutyl-2-stannahexyl)phenyl]methyl]thio}benzenes gave *o*-quinodimethanes which were trapped in situ by dienophiles to give the corresponding cycloadducts in excellent yields. The electron transfer and succeeding 1,4-elimination reaction was efficiently completed in a solution of lithium perchlorate/nitromethane in the presence of acetic acid. The reaction progress was quantitatively controlled by the passage of charge. By using this new method, an aryltetralin lignan skeleton was also synthesized.

It has recently been demonstrated that electrochemical oxidation provides a relatively efficient means of effecting intermolecular carbon−carbon bond formation. The potential of this electrochemical method is highlighted by the general way in which electrochemistry can be used to generate reactive intermediates to construct varied cycloadducts under mild conditions. In this study, we aimed at accomplishing the electrochemical generation and reaction of *o*-quinodimethanes, a goal which has been of great interest in the synthesis of polycyclic compounds.[1]

To date, various methods have been reported for the generation of *o*-quinodimethane intermediates, including the metal-,[2] anion-,[3] or acid-induced,[4] thermal, or photochemical elimination reaction[5] of the corresponding precursors. On the other hand, we anticipate that the electrochemical method also has the potential to play an important role in the generation of unstable *o*-quinodimethanes followed by their cycloaddition with dienophiles. The method is further expected to proceed under the quantitative control of the chemical reaction by regulating the passed charge. Previously, a cathodic generation and Diels−Alder reaction of *o*-quinodimethanes has been accomplished by using 1,2-bis(bromomethyl)benzene.[6] Recently, we accomplished some cycloaddition reactions by using an electrooxidative reaction

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system composed of lithium perchlorate−nitromethane solution.[7] The reaction media have been found to promote the oxidative fission of carbon−sulfur bonds and to show the marked acceleration property of following intermolecular cycloaddition between unactivated alkenes and electrogenerated *o*-quinone methides.[8] It is presumed that the polar ionic solvent system promotes the oxidative fission of C−S bonds and gives an appropriate environment to generate a dipolar compound such as *o*-quinone methide. It is therefore envisioned that *o*-quinodimethanes could be obtained by using the electrochemical induction of the C−S bond fission by the assist of the effective polar, ionic solvent system. We herein report a new method for the electrochemical generation of *o*-quinodimethane intermediates by the oxidative 1,4-elimination of {[[2-(2,2-dibutyl-2-stannahexyl)phenyl]methyl]thio}benzenes.

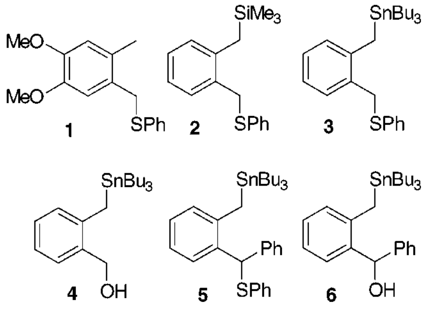
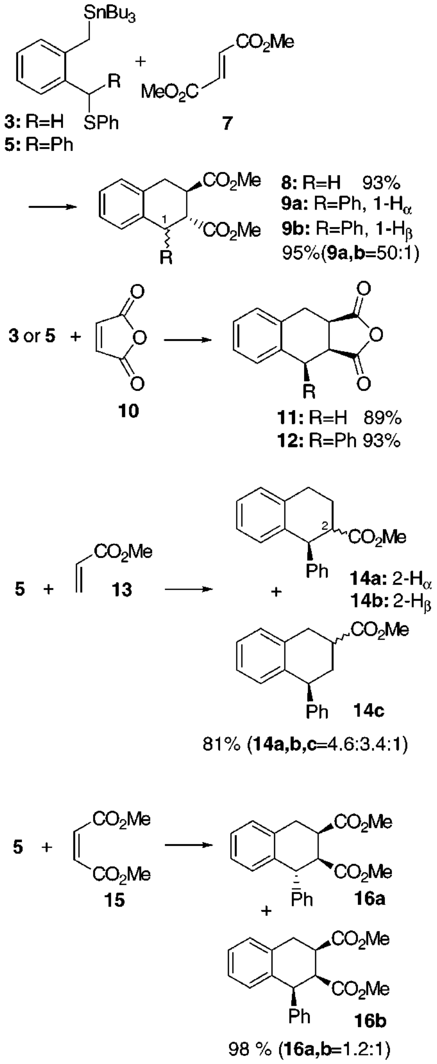


Figure 1. Structures of the substrates for the electrogeneration of *o*-quinodimethanes and related compounds.

Scheme 1



First, to investigate the electrolytic precursor of *o*-quinodimethane, the three sulfides **1**−**3** (Figure 1) were synthesized from 4,5-dimethoxy-2-methylbenzophenone or 2-methylbenzaldehyde (See the Supporting Information and refs 4 and 9). The oxidation potentials of sulfides **1**−**3** in 1.0 M lithium perchlorate−nitromethane were measured by cyclic voltammetry to show clear oxidation potentials at 1.46, 1.15, and 1.17 V (vs SCE), respectively. On the other hand, [*o*-(1-hydroxymethyl)benzyl]tributylstannane (**4**) showed no oxidation peak below 1.8 V vs SCE. These results indicated that the electron-releasing groups at the *o*-methyl group decreased the oxidation potentials of sulfides. The electrooxidation of these sulfides was performed in 1.0 M lithium perchlorate−nitromethane, 0.1 M AcOH, in the presence of dimethyl fumarate (**7**), using glassy carbon as an anode and Pt as a cathode. Electrooxidation of compound **1** or **2** gave a small amount of the corresponding sulfoxide and messy products with no desired cycloadduct. Trimethylsilyl and phenylsulfanyl groups of **2** did not eliminate under these conditions. On the other hand, the electrooxidation of compound **3** at 70 °C gave the desired cycloadduct **8** in 93% yield (Scheme 1). Compound **5** also showed an oxidation peak at 1.10 V vs SCE; in contrast, such a peak was not observed for compound **6** below 1.8 V vs SCE. The electrooxidation of **5** at the peak potential with maleic anhydride **10** successfully gave cycloadduct **12** at ambient temperature in excellent yields. The oxidative cycloaddition of **5** with methyl acrylate **13** gave a mixture of isomers **14a**−**c** in moderate yields (**14c** is a single stereoisomer of unknown stereoisomer). The stereochemistry of cycloadducts **9**, **12**, **14**, and **16** was established by an ^{1}H NMR study. The difference in the reactivities between **3** and **5** should depend on the stability of corresponding benzyl cation intermediates. We also confirmed that these reactions did not proceed when

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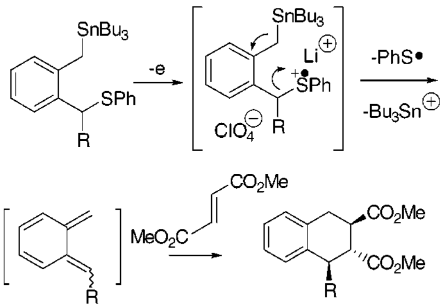

Figure 2. Proposed mechanism of the electrochemical generation and Diels−Alder reaction of *o*-quinodimethanes. It is presumed that the electron-donative property of the tributylstannyl group, stabilization of the benzyl carbocation by perchlorate ion, and the Lewis acidity of the lithium ion assist the electrooxidative elimination of phenylsulfanyl radical followed by the fission of the C−Sn bond to generate the corresponding *o*-quinodimethanes.

the reaction mixture was just allowed to stand in the solvent system without the application of voltage, and the starting materials were almost completely recovered. During the electrolysis of **5**, the yield of the product increased with the amount of passed charge, and the reaction was completed after ca. 1.2 faraday/mol of charge. In the presence of a small amount of AcOH, the electrolysis proceeded efficiently in higher current density. In addition, the electrolytic Diels−Alder adducts were scarcely obtained in other usual combinations of electrolyte and solvent such as in 0.1 M tetraethylammonium *p*-toluenesulfonate−acetonitrile even in the presence of 0.1 M AcOH. The results suggested that the lithium perchlorate−nitromethane system is essential to generate *o*-quinodimethane from the present substrates. According to our data, the tributylstannyl group and the reaction media might assist in the oxidative release of the phenylsulfanyl radical, followed by the release of the tributylstannyl group, to generate the *o*-quinodimethanes (Figure 2).

In conclusion, a new, mild method for the generation of *o*-quinodimethane intermediates initiated by electrooxidation has been accomplished. Under the regulation of charge transfer, the generation and Diels−Alder reaction of *o*-quinodimethane was successfully controlled to give desired cycloadducts in excellent yields, including those possessing natural aryltetralin lignan skeletons.

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Supporting Information Available: General procedure for the synthesis of **3**, **5**, the electrochemical synthesis of cycloadducts, and selected NMR data for **3**, **5**, **9a**, **9b**, **12**, **16a**, and **16b**. This material is available free of charge via the Internet at http://pubs.acs.org.

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