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ORGANOTHIO GROUPS AS ELECTROAUXILIARIES: ELECTROOXIDATIVE INTER- AND INTRAMOLECULAR CARBON-CARBON BOND FORMATION

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Abstract: Anodic oxidation of α -organothio ethers results in the cleavage of the carbon-sulfur bond and the introduction of carbon nucleophiles onto the carbon, suggesting the effectiveness of organothio groups as electroauxiliaries. Copyright © 1996 Elsevier Science Ltd

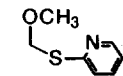
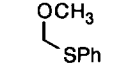
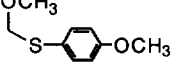
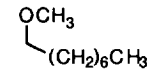
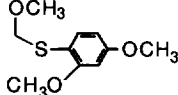
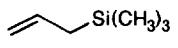
Electroauxiliary, which activates organic molecules for electron transfer and controls the fate of thus generated reactive intermediates, has emerged as an important concept in electroorganic synthesis.¹ Recently we have demonstrated that silicon and tin are efficient electroauxiliaries in anodic oxidation of heteroatom compounds.² In order to establish the generality of this concept, we have investigated other types of electroauxiliaries and herein we wish to report that organothio groups serve as an effective electroauxiliary for the anodic oxidation of heteroatom compounds.

Several studies on electron-transfer reactions of α -organothio-substituted heteroatom compounds to cleave the carbon-sulfur bond generating carbocation intermediates have been reported.³ On the basis of these studies, we envisioned that organothio groups could be used as electroauxiliaries in the anodic oxidation of heteroatom compounds. Although the reactions of the carbocation intermediates with heteroatom nucleophiles such as alcohols have been studied extensively,³ little work has been carried out on the use of carbon nucleophiles to achieve carbon-carbon bond formation.⁴ In this paper we describe anodic oxidation of α -organothio-substituted ethers in the presence of carbon nucleophiles leading to inter- and intramolecular carbon-carbon bond formation.

The oxidation potentials of α -organothio ethers are much less positive than those of the corresponding ethers as shown in Table 1, although they are slightly more positive than those of the corresponding sulfides. This fact is in sharp contrast with the cooperative effect between silicon and tin with oxygen to decrease the oxidation potentials. In the cases of silicon and tin, the carbon-metal σ bond interacts with the nonbonding p orbital of the oxygen to raise the HOMO level which, in turn, favors the electron transfer.^{1,2} In the case of sulfur, however, such interaction is absent. The electron transfer takes place mainly from the sulfur atom. Molecular orbital calculations, however, indicated that there is a significant interaction between the p orbital of the oxygen atom and the C-S σ orbital in the cation radical intermediate.

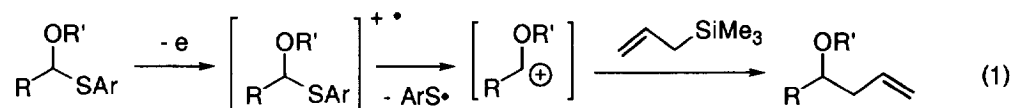
It is interesting that the oxidation potentials of α -organothio ethers can be tuned by changing the nature of the substituent on the sulfur atom as shown in Table 1. The oxidation potentials of phenylthio-, 4-methoxyphenylthio-, and 2,4-dimethoxyphenylthio-substituted ethers are less positive than that of allyltrimethylsilane, suggesting that the allylsilane can be used as a nucleophile in the anodic oxidation, whereas the oxidation potential of the 2-pyridylthio-substituted ethers is more positive than that of allyltrimethylsilane.

Table 1. Oxidation Potentials Organothio-Substituted Ethers and Related Compounds ^a

Compound	E _d (V)	Compound	E _d (V)
	1.78		
	1.40	CH ₃ SPh	1.24
	1.18		> 2.3
	1.00		1.53

^a The oxidation potentials (decomposition potentials; E_d) were determined with rotating disk electrode voltammetry using a glassy carbon working electrode in 0.1 M LiClO₄/CH₃CN. A Ag/AgCl electrode was used as a reference electrode.

The intermolecular carbon-carbon bond formation with an allylsilane has been achieved by using the arylthio groups as electroauxiliaries. Preparative constant current electrolysis of α -arylthio ethers in the presence of allyltrimethylsilane proceeded smoothly in an undivided cell equipped with a carbon rod anode and a platinum plate cathode in Bu₄NClO₄/CH₂Cl₂. The C-S bond was cleaved and an allyl group was introduced onto the carbon (eq 1 and Table 2).⁵ This result contrasts with the predominant C-O cleavage in the Lewis acid-catalyzed reactions of α -alkoxyalkyl phenyl sulfides with allylsilanes.⁶



Allyl aryl sulfides and diaryl disulfides were obtained as sulfur containing products, indicating that the arylthio radical was formed by the cleavage of the C-S bond. Dimerization of the arylthio radical gave the diaryl disulfides. The allyl aryl sulfide seemed to be formed by the addition of the arylthio radical to the allylsilane followed by the anodic oxidation to generate the carbocation β to silicon which underwent facile β -elimination to give the allyl aryl sulfides. The formation of the arylthio radical suggests that the cleavage of the C-S bond in the initially formed cation radical leads to the formation of the carbocation adjacent to the oxygen atom which reacts with allyltrimethylsilane to give the product (eq 1).

The intramolecular carbon-carbon bond formation was also achieved by the anodic oxidation of α -phenylthio- and α -methylthioethers having a carbon-carbon double bond. The anodic oxidation in Bu₄NBF₄ or Bu₄NPF₆/CH₂Cl₂ gave rise to the cleavage of the C-S bond and the C-C bond formation with one of the olefinic carbons and the introduction of fluoride onto the other olefinic carbon.⁷ In this case the carbon-carbon double bond acted as a carbon nucleophile for the initially formed carbocation intermediate. It is interesting that Bu₄NBF₄ and Bu₄NPF₆ as the fluoride sources exhibited different stereoselectivity, although the reason is not clear at present.

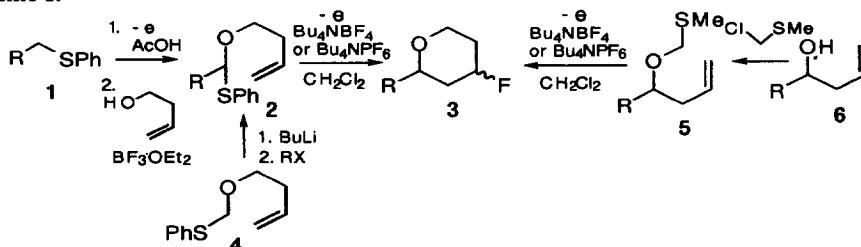
Table 2. Electrooxidative Inter- and Intramolecular Carbon-Carbon Bond Formation Using Organothio Groups as Electroauxiliaries^a

Substrate	Nucleophile	Supporting electrolyte	Electricity (F/mol)	Product ^b	Yield (%) ^c
		Bu ₄ NClO ₄	1.8		61 (70)
		Bu ₄ NClO ₄	1.3		(81)
		Bu ₄ NBF ₄	4.4		(76)
		Bu ₄ NClO ₄	1.6		(46)
		Bu ₄ NClO ₄	2.1		53
	-	Bu ₄ NBF ₄	2.2		64
	-	Bu ₄ NBF ₄	3.5		61
	-	Bu ₄ NPF ₆	2.4		(87)

^a Reactions were usually carried out with 0.5 mmol of α -organothio ether in the presence or in the absence of an allylsilane (2 equiv) in CH₂Cl₂ at room temperature. ^b The ratio of diastereomers was determined by ¹H NMR. ^c The isolated yields. The yields in parentheses were determined by ¹H NMR using an internal standard.

The synthetic versatility of organothio groups together with the fact that they are less toxic than tin is advantageous. For example, the anodic acetoxylation⁸ of phenyl alkyl sulfide (1) followed by Lewis acid catalyzed substitution with homoallyl alcohol⁹ gave compound 2 that was subjected to anodic oxidation in Bu₄NBF₄/CH₂Cl₂ to yield compound 3 (R = C₉H₁₉) as shown in Scheme 1. Compound 2 was also prepared by lithiation¹⁰ of homoallyl phenylthiomethyl ether (4) followed by alkylation with an alkyl halide. Compound 3 (R = C₇H₁₅) was also synthesized by anodic oxidation of compound 5, which was easily prepared by the reaction of homoallyl alcohol 6 with chloromethyl methyl sulfide.¹¹

Scheme 1.



The research reported above demonstrates not only the utility of organothio groups as electroauxiliaries in oxidation of heteroatom compounds but also the generality of the concept of electroauxiliary. It is hoped that exploitation of various kinds of electroauxiliaries will enable problems of chemo- and regioselectivity in electron-transfer reactions to be overcome satisfactorily. Further work is in progress to explore the full scope of the concept of electroauxiliary and its applications to the synthesis of various organic compounds.

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