Pergamon

Tetrahedron Letters, Vol. 37, No. 35, pp. 6391-6394, 1996
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0040-4039/96 $15.00 + 0.00

PII: S0040-4039(96)01355-X

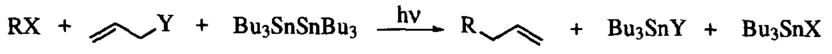
Tris(trimethylsilyl)silane as Mediator in the Radical-Based Allylation Reactions of Allyl and 2-Functionalized Allyl Phenyl Sulfones

Chryssostomos Chatgilialoglu,* Angelo Alberti, Marco Ballestri and Dante Macciantelli
I.Co.C.E.A., Consiglio Nazionale delle Ricerche, Via P. Gobetti 101, 40129 Bologna, Italy

Dennis P. Curran
Department of Chemistry, University of Pittsburgh, Pittsburgh, PA 15260, USA

Abstract: Radical allylations with 2-functionalized allyl phenyl sulfones have been performed by using tris(trimethylsilyl)silane as radical mediator. Yields varied from moderate to good depending on the nature of the starting materials. EPR studies on the alkyl radical adducts of allyl sulfones have been performed and conformational information has been obtained for the *tert*-butyl and tetrahydrofuranyl adducts of 2-carboxy allyl tris(trimethylsilyl)silane. Copyright © 1996 Elsevier Science Ltd

In the preceding two papers, we reported the synthesis of allyl and 2-functionalized allyl tris(trimethylsilyl)silanes and their use as allylating agents. Here we extend the allylation concept of Keck and coworkers that is outlined in equation 1.[1-3]



(1)

Y = SPh, SO_2Ph, Cl

Allylation of radical precursors with allyl phenyl sulfides and related molecules occurs upon irradiation in the presence of stoichiometric quantities of hexabutylditin.[1-3] The propagation steps for these transformations consist of an attack of a carbon-centered radical on the allyl fragment followed by a β-elimination of the Y• radical, which then attacks the ditin in a S_H2 fashion to give the tin radical. Abstraction of the halogen from the alkyl halide completes the cycle of these chain reactions.

The basic transformation that we conceive is summarized in equation 2.[4] The choice of allyl sulfones instead of allyl sulfides is dictated by the fact that benzenesulfinic acid does not release a hydrogen atom under normal conditions whereas the benzenethiol is an extremely good hydrogen donor.[5]

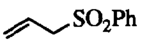
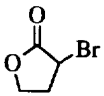
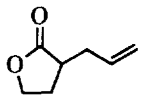
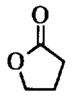
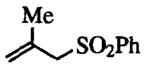
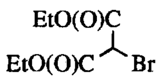
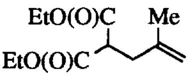
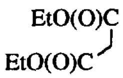
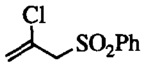
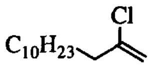
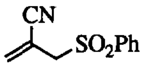
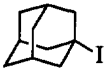
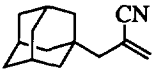
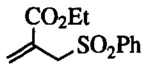
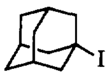
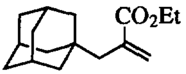
(2)

Z = H, Me, Cl, CN, CO_2Et

Initial reactions conducted by standard radical procedures were unsuccessful; only the direct reduction products of alkyl halides were observed. However, under high dilution of $(TMS)_3SiH$ (achieved by adding the silane to the reaction mixture by syringe-pump) and a 3 to 4-fold excess of the allylating agent, allylation competes with reduction. Table 1 records the precursors, conditions, products and yields for several of such reactions. In general, the more electron rich allyl-, methallyl, and 2-chloro allyl phenyl sulfones were found to react with moderately or strongly electrophilic radicals in modest yields, while the electron poor 2-cyano and 2-carboethoxy allyl phenyl sulfones reacted with nucleophilic radicals in good yields .

A plausible mechanism, which served as the working hypothesis for the performance of these reactions, can be written as shown in Scheme 1. In order to have an efficient allylating system, a rapid elimination of the leaving $PhSO_2$ group is required once the intermediate radical is formed. The effectiveness of the β-elimination of sulfonyl radicals is well documented in radical-based synthetic applications.[4,6] Since the C–S bond must eclipse the orbital containing the unpaired electron for β-elimination to take place, we have carried out EPR

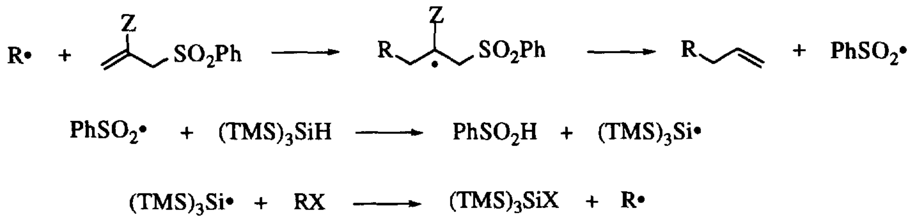
Table 1. $(TMS)_3SiH$ as mediator for allylation reactions using allylic phenyl sulfones with alkyl halides

Allylating Agent	Alkyl Halide[a]	Reactant Ratios[b] and Conditions[c,d]	Allylating Product[e]	Reducing Product[e]
		3:1:1.5 / SP-6h	 35%	 36%
		4:1:1.3 / SP-8h	 36%	 51%
	$C_{10}H_{23}$—I	4:1:1.3 / SP-6h	 42%	$C_{10}H_{24}$ 53%
		3:1:2 / SP-6h	 74%	 20%
		3:1:2 / SP-4h	 82%	 15%

[a] 0.2 M in benzene. [b] The ratios are referred to [allylating agent]:[alkyl halide]:[$(TMS)_3SiH$]. [c] AIBN at 80 °C. [d] SP = Syringe-Pump experiments. [e] GC yields. .

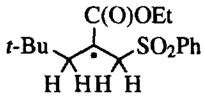
experiments aimed at determining the conformation of the radicals resulting from addition of carbon-centered radicals to allyl sulfones. Due to solubility problems associated with the starting materials at low temperatures, the EPR study was limited to allyl and 2-carboethoxy allyl phenyl sulfones.

Scheme 1



Photolytic generation of tetrahydrofuranyl and *tert*-butyl radicals[7] in the presence of allyl phenyl sulfone showed the formation of the PhSO$_2^•$ radical (a_{2H} 0.33, a_{2H} 0.95, a_H 0.55 G g 2.00437)[8] as the only detectable species in the temperature range –70 to –10 °C. Because the PhSO$_2^•$ radical could not be detected by direct photolysis of the allyl phenyl sulfone, we deduced that addition of the two alkyl radicals to the carbon-carbon double bond must take place, followed by a rapid β-elimination of PhSO$_2^•$ radical.

The appropriate radical adducts were instead observed by addition of tetrahydrofuranyl and *tert*-butyl radicals to 2-carboethoxy allyl phenyl sulfone; they gave virtually identical spectra (structure **1**), the only difference being that the hyperfine structure from the carboethoxy group was not resolved in the tetrahydrofuranyl adduct.



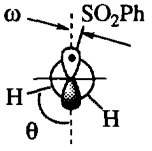
1

$a_{H\beta}$: 6.2, 7.1, 15.7 G and 16.9 G

others : a_H 1.2, a_H 1.6 G and a_{3H} 0.4 G

Conformational information can be obtained by applying the simplified Heller-McConnell equation, i.e. $a_{H\beta} = B\langle\cos^2\theta\rangle\rho_{C\alpha}$.[9] The determination of the dihedral angle θ between the C_β–H bond and the orbital containing the unpaired electron (see structures **2** and **3**) requires the knowledge of B (normally taken as 48 G) and the spin density at the radical centre ($\rho_{C\alpha}$). However, the value of $B\rho_{C\alpha}$ can be estimated from the hydrogen hfs constant of a methyl group that replaces the $C_\beta H_2X$ moiety in a structurally related radical, the ensemble average $\langle\cos^2\theta\rangle$ being equal to 0.5 for a freely rotating methyl group. Since the hfs constant of methyl hydrogens in $CH_3C(^•)(COOEt)CH_2R$ are known to be 22.18 G,[10] we calculate a value of 44.36 G for $B\rho_{C\alpha}$ for radical **1**. The hydrogens from each methylene group should be characterized by a small and a large hfs constant. Although it is impossible to tell from the experimental results which pair of hfs should be assigned to each individual methylene group, it is nevertheless evident that both PhSO$_2$ and R group eclipse almost completely the orbital containing the unpaired electron (ω and ϕ in **2** and **3**, respectively, are less than 10°). It should also be noted that the two pairs of methylene protons are magnetically non-equivalent even at the highest investigated temperature, i.e. -10 °C, with no significant signs of linewidth alternation. This indicates that rotation about the

CH_2-C($^\bullet$)-CH_2 bonds is almost completely frozen out on the EPR timescale even at temperatures close to 0 °C, suggesting structure **4** as the most appropriate candidate.



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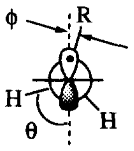

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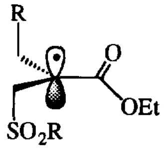

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The EPR results thus give support to the mechanism outlined in Scheme 1 which satisfactorily describe the radical-based allylation reactions.

Acknowledgments: C.C. and D.P.C. thank NATO for a grant which made this collaboration possible. C.C. also thanks the Progetto Strategico "Tecnologie Chimiche Innovative" (CNR-Rome) for some financial support. D.P.C. thanks the US NSF and NIH for support.

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(*Received in UK* 17 *May* 1996; *revised* 8 *July* 1996; *accepted* 12 *July* 1996)