Pergamon

Tetrahedron Letters 40 (1999) 3973–3976

TETRAHEDRON
LETTERS

Oxidation of α-Hydroxysilanes by Lead Tetraacetate

María Dolores Paredes and Ricardo Alonso*

Departamento de Química Orgánica y Unidad Asociada al CSIC,
Universidad de Santiago de Compostela, 15706 Santiago de Compostela, Spain. E-mail: qoraa@correo.usc.es

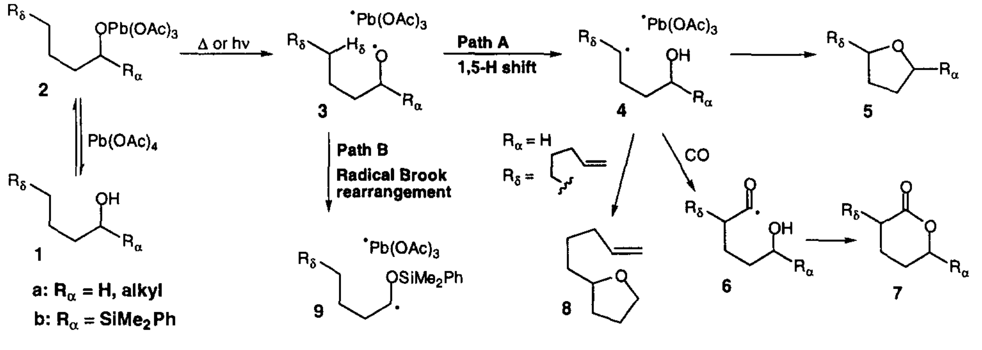
Received 11 January 1999; revised 22 March 1999; accepted 29 March 1999

***Abstract*:** The effect of α-silyl substitution on the oxidation of alcohols by lead tetraacetate has been evaluated. Under typical conditions for converting alcohols to cyclic ethers, α-hydroxysilanes are instead efficiently transformed into mixed acetyl-silyl acetals. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: α-hydroxysilane; lead tetraacetate; radical Brook rearrangement; α-silyloxy carbon radicals; mixed acyl-silyl acetals.

It is well known that treatment of monohydroxy alcohols such as **1a** with lead tetraacetate (LTA)[1] results in rapid equilibration with alkoxylead(IV) acetates **2a**, which in non-polar solvents mainly evolve, under appropriate thermal or photochemical conditions, to alkoxy radicals **3a**. Saturated radicals **3a** with an accessible hydrogen atom at the δ carbon then take Path A of Scheme 1: the δ carbon hydrogen transfers to the oxygen to afford carbon radicals **4**, which generally undergo fast oxidative cyclization to ethers **5**[2] (though intermolecular trapping of carbon radicals **4** by carbon monoxide to afford δ-lactones **7** *via* intermediates **6** has recently been reported,[3] the readiness with which the oxidative cyclization occurs is well illustrated by taking R_α = H and $R_\delta = (CH_2)_3CH{=}CH_2$, in which case cyclization to **8** pre-empts 1,5-*exo* trig intramolecular addition to the double bond).[4]

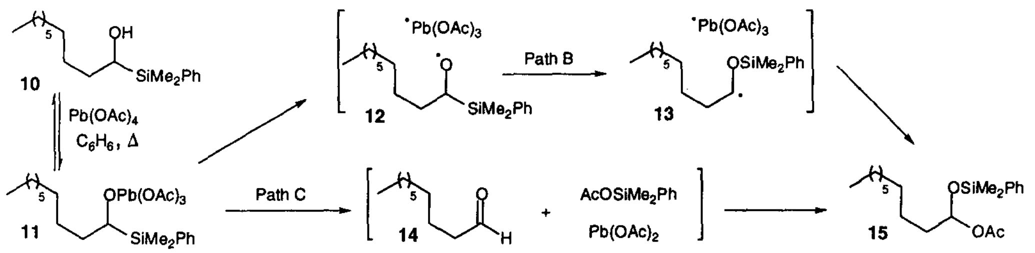
Scheme 1



Noting that for silylated alkoxy radicals **3b**, obtained by starting from α-silyl substituted alcohols **1b**, Path A would have to compete with a low energy radical Brook rearrangement to α-silyloxy carbon radicals **9** (Path B in Scheme 1),[5] and that preference for Path B could make α-hydroxysilanes **1b** new precursors of these latter species,[6,7] we prepared **10** from decanal and phenyldimethylsilyllithium[8] and subjected it to standard LTA oxidation conditions (110 mol% of LTA, refluxing benzene, Scheme 2). The exclusive product **15** (73% isolated yield), was initially assumed to have been formed by Path B *via* the α-silylalkoxy radical **12** and the α-silyloxy carbon radical **13**, i.e. that in fact the Brook rearrangement to generate α-silyloxy carbon radicals was indeed faster than 1,5-hydrogen transfer.

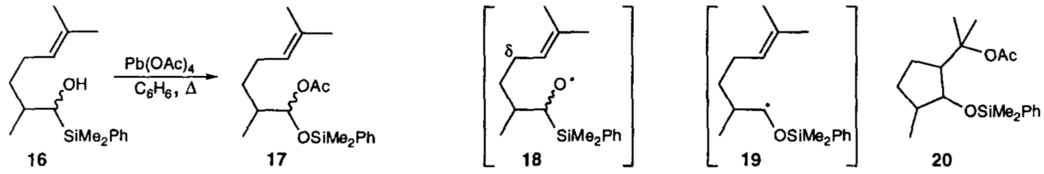
PII: S0040-4039(99)00646-2

Scheme 2



Accordingly we next decided to investigate wether α-silyloxy carbon radical intermediates of type **9** could undergo other transformations, such as radical cyclization, if endowed with a suitable internal radical trap.[9,10] To this end, we treated α-hydroxysilane **16** with 100 mol% of LTA in refluxing benzene, but the exclusive product was the mixed silyl-substituted acetal **17**; no cyclized products such as **20** were formed (Scheme 3). We attributed this result to the Brook rearrangement of the hypothetical radical intermediate **18** being faster than both hydrogen transfer from the activated allylic δ-carbon and 1,6-*exo* cyclization of the alkoxy radical to the double bond, and to oxidation of the resulting α-silyloxy carbon radical **19** being faster than its 1,5 addition to the double bond; this behaviour was taken to be in keeping with that of the δ carbon radical analogue **4** [R_α = H and $R_\delta = (CH_2)_3CH{=}CH_2$].[11]

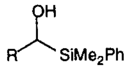
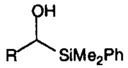
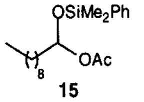
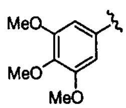
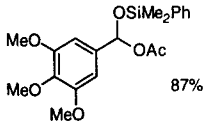
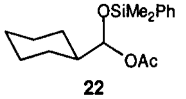
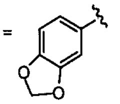
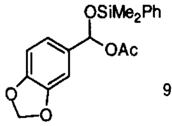
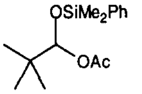
Scheme 3



The reactions of other, differently substituted alkyl and aryl α-hydroxysilanes were similar to those of **10** and **16** (Table 1).[12] However, during these experiments we realized that it was not necessary to run the reaction in refluxing benzene or to use excess LTA. The transformation of all the α-hydroxysilanes used, including **10** and **16**, into the corresponding mixed silyl-substituted acetals took place at room temperature, almost instantaneously, and in essentially quantitative yield (as determined by ^{1}H NMR of the reaction mixtures) with just one equivalent of LTA. This is in marked contrast to standard radical-mediated lead tetraacetate oxidation reactions, in which the starting monohydroxy alcohols are recovered in significant quantities even when longer reflux times and LTA:alcohol mole ratios of up to 3:1 are used.[13] It should also be noted that although alkoxy radicals can be obtained from alcohols by LTA treatment at temperatures as low as 40°C (as demonstrated by their transformation into δ-lactones),[3] the long reaction times that are required (1 day with a 1.5:1 LTA:alcohol mole ratio), appear to show that homolysis at that temperature is very slow. In view of this, the reaction path **10** → **11** → **12** → **13** → **15** (Scheme 2), requires that homolysis of the Pb-O bond in **11** be greatly favoured by the geminal silyl substituent. An alternative mechanism would be the elimination of the lead(II) and silicon species $Pb(OAc)_2$ and $AcOSiMe_2Ph$ from the alkoxylead(IV) acetate **11** to give an intermediate aldehyde (**14**) which would then react to give the final acetal **15** (Path C in Scheme 2).

It may be noted that the mixed acyl-silyl acetals obtained in this study, though rather unusual,[14] have been used to protect aldehyde groups,[15] and in reactions with silyl enol ethers and allyltrimethylsilane in the presence of a Lewis acid.[16] They have also been reduced by DIBALH,[17a] and efficiently hydrolysed under both acidic[18] and basic[17] conditions to the corresponding aldehydes. In this respect, we noted that the aromatic acetals obtained are particularly prone to undergo hydrolysis; in fact, acetals **26** and **28** underwent complete conversion to the carbonyl derivatives on filtration through silica gel or alumina.

Table 1

	Product	yield		Product	yield
R = $CH_3(CH_2)_8$- **10**	 **15**	73% [a] 84% [b]	R =  **25**	 **26**	87% [c]
R = cyclohexyl- **21**	 **22**	71% [a] 93% [b]	R =  **27**	 **28**	92% [b,d]
R = $(CH_3)_3C$- **23**	 **24**	78% [a] 92% [b]			

a) Yields after isolation by column chromatography. Reactions performed with LTA (110 mol%) in refluxing benzene at the 100 mg scale.

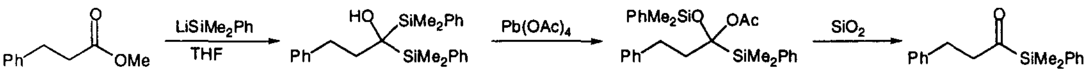
b) To a solution of the α-hydroxysilane (0.04-0.05 mmol) in 0.5 mL of C_6D_6 prepared in an NMR tube were added 1,4-dichlorobenzene (6 mg) and $Pb(OAc)_4$ (100 mol%). The tube was shaken for about 2 min (measured internal T ≅ 35 °C)[19] and immediately subjected to proton NMR spectroscopy, which showed complete transformation. Yield was estimated by integration of the well-defined NMR signal of the acetal proton of the product, using 1,4-dichlorobenzene as the internal standard.

c) Standard LTA oxidation conditions, 100 mg scale. The ^1H NMR of the crude residue obtained by filtration of the reaction mixture and concentration under reduced pressure showed an 87:13 ratio of **26** versus the corresponding aldehyde. Filtration of this mixture through alumina or silica gel gave the aldehyde in quantitative yield.

d) When the reaction was performed in refluxing benzene (100 mg scale), chromatography isolated piperonal and its monoacetoxy derivative at the isopropylidene group in 58% and 37% yield, respectively.

Finally, to determine whether quaternary α-silylalcohols undergo the same type of transformation, we carried out the reaction on the bis-silyl-substituted hydroxy derivative **30**, which was obtained from the ester **29**. Oxidation of **30** with LTA afforded the desired acetal **31** in 94% yield (as judged by NMR), and treatment of the crude reaction mixture with silica gel resulted in clean hydrolysis to the acylsilane **32** (Scheme 4). This sequence constitutes a synthetic pathway to acylsilanes from esters.[20]

Scheme 4



In summary, placing a silyl group α to the hydroxyl of a monohydroxy alcohol radically changes its reaction with lead tetraacetate, which affords a high yield of the mixed silyl-substituted acetal instead of a cyclic ether. Furthermore, this reaction is much faster and cleaner, and takes place under much milder conditions, than one would expect from the behaviour of the unsubstituted alcohol. Although a radical-based mechanism based on fast Brook rearrangement of radicals **3b** followed by oxidation of the resulting intermediates **9** cannot be ruled out on the basis of current data, failure to obtain cyclic products such as **20**, and the dramatic rate-accelerating effect of the geminal silicon atom, point to an alternative ionic mechanism (Path C in Scheme 2).

Acknowledgment

This research was supported financially by the Xunta de Galicia (XUGA 20902B97) and the DGES (PB95-0824). The Xunta de Galicia is also thanked for a predoctoral grant to María Dolores Paredes.

References and Notes

1. Mihailovic M. Lj.; Cekovic, Z. in *Encyclopedia of Reagents for Organic Synthesis*. Paquette, L. A., Ed.; John Wiley and Sons: Chichester, 1995; Vol. 5; pp 2949-2954 and references cited therein. For another leading review see Heusler, K.; Kalvoda, J. *Angew. Chem., Int. Ed. Engl.* **1964**, *3*, 525-538.
2. A detailed and well-documented mechanistic description of the oxidation of monohydroxy alcohols by LTA is given by Mihailovic M. Lj.; Cekovic, Z.; Lorenc, Lj. in *Organic Synthesis by Oxidation with Metal Compounds*; Mijs, W. J.; de Jonge, C. R. H. I., Eds.; Plenum Press: New York 1986; Chapter 14, pp 741-816. They note, *inter alia*, that i) lead(IV) alkoxides similar to **2** but with more than one alkoxy group can also be formed; ii) evidence for the formation of alkoxy radicals **3** has been obtained from esr studies and from the isolation of epimeric products derived from reversible fragmentation of these intermediates; iii) the *β*-fragmentation and oxidation of alkoxy radicals **3** are usually minor pathways when intramolecular hydrogen abstraction is feasible; iv) the possibility of direct conversion of alkoxy radicals **3** to ethers **5** has been suggested in the case of conformationally fixed systems; and v) in acyclic and monocyclic systems with a double bond adjacent to a *δ*- or *ε*-carbon atom, internal addition of the alkoxy radical to the carbon-carbon double bond is the preferred reaction.
3. Tsunoi, S.; Ryu, I.; Okuda, T.; Tanaka, M.; Komatsu, M.; Sonoda, N. *J. Am. Chem. Soc.* **1998**, *120*, 8692-8701.
4. The authors suggested that the putative carbon radical **4** [R_α = H and $R_\delta = (CH_2)_3CH=CH_2$] constitutes a tight radical pair with a lead(III) species, e.g. $\bullet Pb(OAc)_3$: Cekovic, Z.; Ilijev, D. *Tetrahedron Lett.* **1988**, *29*, 1441-1444.
5. The radical Brook rearrangement was first suggested to explain the formation of cyclopropanes by photoreaction of acylsilanes and electron-poor olefines: Dalton, J. C.; Bourque, R. A. *J. Am. Chem. Soc.* **1981**, *103*, 699-700. It was first used synthetically (for formation of cyclopentanols and cyclohexanols from *δ*- and *ε*-halogenated acylsilanes, respectively) ten years later: Tsai, Y.; Cherng, C. *Tetrahedron Lett.* **1991**, *32*, 3515-3518. For more recent references see: Chang, S.; Jiaang, W.; Cherng, C.; Tang, K.; Huang, C.; Tsai, Y. *J. Org. Chem.* **1997**, *62*, 9089-9098. For an esr study of this rearrangement, see Harris, J. M.; MacInnes, I.; Walton, J. C.; Maillard, B. *J. Organomet. Chem.* **1991**, *403*, C25-C28. An *ab initio* study (Schiesser, C. H.; Styles, M. L. *J. Chem. Soc., Perkin Trans. 2* **1997**, 2335-2340) suggests front-side transfer of the silyl group. For a mechanistic discussion of the Brook rearrangement in connection with a new carbon-to-carbon 1,2-silyl migration of *β*-silyl carbon radicals, see Shuto, S.; Kanazaki, M.; Ichikawa, S.; Minakawa, N.; Matsuda, A. *J. Org. Chem.* **1998**, *63*, 746-754.
6. J. Robertson and coworkers attempted to use epoxysilanes as precursors of *α*-silyloxy carbon radicals. In their preliminary experiments they found, however, that the *γ,δ*-unsaturated *α*-silyl-substituted alkoxy radical intermediates suffered ejection of a silyl radical instead of the expected radical Brook rearrangement: Robertson, J.; Burrows, J. N. *Tetrahedron Lett.* **1994**, *35*, 3777-3780.
7. α-Alkoxy carbon radicals have been extensively used in synthesis. For the particular case of *α*-silyloxy carbon radicals, see for example: Corey, E. J.; Pyne, S. G. *Tetrahedron Lett.* **1983**, *24*, 2821-2824.
8. For the preparation of α-hydroxysilanes see Chenede, A.; Abd.Rahman, N.; Fleming, I. *Tetrahedron Lett.* **1997**, *38*, 2381-2382 and references cited therein.
9. Alkoxy radicals generated by radical cyclization onto acylsilanes have been successfully used in radical Brook/C-C bond forming reactions by means of inter and intramolecular trapping sequences: Tsai, Y.; Tang, K.; Jiaang, W. *Tetrahedron Lett.* **1996**, *37*, 7767-7770 and references cited therein.
10. For an extensive list of references on alkoxy radical generation/1,5-H shift/ C-heteroatom or intramolecular C-C bond formation sequences using various alkoxy radical formation methods, see ref 5. For analogous sequences with intermolecular C-C bond formation see: (a) López, J. C.; Alonso, R.; Fraser-Reid, B. *J. Am. Chem. Soc.* **1989**, *111*, 6471-6473. (b) Petrovic, G.; Cekovic, Z. *Tetrahedron Lett.* **1997**, *38*, 627-630. (c) Petrovic, G.; Saicic, R. N.; Cekovic, Z. *Tetrahedron Lett.* **1997**, *38*, 7107-7110.
11. Oxidation of intermediates **9** should be even faster than that of **4** because of their greater nucleophilicity.
12. This is the first reported method for direct conversion of *α*-hydroxysilanes to acetals. It complements the known oxidations of these substrates to aldehydes: (a) Fleming, I.; Ghosh, U. *J. Chem. Soc. Perkin Trans. 1* **1994**, 257-262, and to acylsilanes: (b) Ireland, R. E.; Norbeck, D. W. *J. Org. Chem.* **1985**, *50*, 2198-2200.
13. Partch, R. E. *J. Org. Chem.* **1965**, *30*, 2498-2502 and Mihailovic, M. Lj.; Cekovic, Z.; Maksimovic, Z.; Jeremic, D.; Lorenc, Lj.; Mamuzic, R. I. *Tetrahedron* **1965**, *21*, 2799-2812.
14. A search of Chemical Abstracts for acyl-silyl acetal substructures found just 23 references between 1967 and mid 1997.
15. Mander, L. N.; Owen, D. J. *Tetrahedron*, **1997**, *53*, 2137-2162.
16. Shaw, J. T.; Woerpel, K. A. *J. Org. Chem.* **1997**, *62*, 442-443. Shaw, J. T.; Woerpel, K. A. *J. Org. Chem.* **1997**, *62*, 6706-6707.
17. (a) Álvarez, E.; Rico, M.; Rodríguez, R. M.; Zurita, D.; Martín, J. D. *Tetrahedron Lett.* **1992**, *33*, 3385-3388. (b) Deprotection with KF has also been reported: Giese, B.; Horler, H. *Tetrahedron* **1985**, *41*, 4025-4037.
18. Duff, J. M.; Brook, A. G. *Can. J. Chem.* **1973**, *51*, 2869-2883. Nakatani, S.; Yoshida, J.; Isoe, S. *Tetrahedron*, **1993**, *49*, 2011-2024.
19. The NMR tube was held vertically with a cloth and moved rapidly to and fro in this "sheath".
20. For the preparation of **30** and its oxidation to **32** see ref. 12a.