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BASE-INDUCED REACTIONS OF α,β-DIHYDROXYSILANES: STEREOCHEMISTRY AND MECHANISMS

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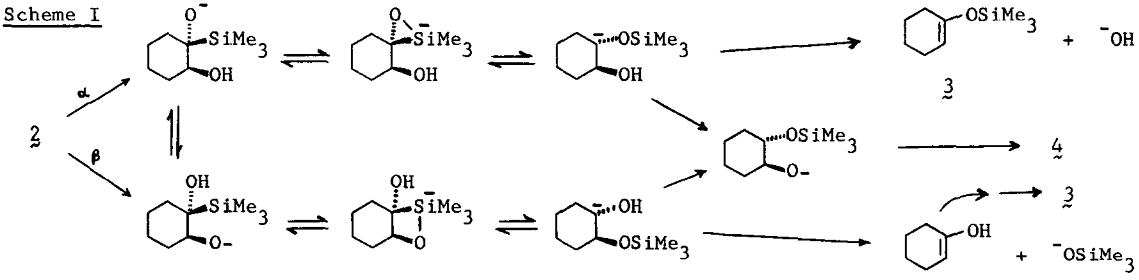
Abstract: Cyclic α,β-dihydroxysilanes undergo base-induced elimination reactions if the silicon and the β-OH can be anti; otherwise protiodesilylation predominates.

In the preceding communication,[2] we reported that the synthesis of heteroatom-substituted olefins via α,β-epoxysilanes[3] can be extended to the preparation of acyclic silyl enol ethers, although not with the expected stereochemistry. It was suggested that the base-induced elimination reactions of the intermediate α,β-dihydroxysilanes take place by pathways involving α-oxidosilanes in competition with the well known β-elimination reactions[4,5] of β-oxidosilanes. We have begun to investigate the corresponding reactions in cyclic systems; these reactions demonstrate that the base-induced elimination reactions of α,β-dihydroxysilanes can take place by the α-oxidosilane pathway, and that the stereochemistry of this process is preferentially anti.

1-Trimethylsilylcyclohexene oxide (1) was converted to the α,β-dihydroxysilane 2 by treatment with $H_2O/THF/H_2SO_4$ as previously described.[6] Treatment of 2 with KH followed by Me_3SiCl gave, at most, only small amounts of the expected silyl enol ether 3; the major product was trans-1,2-bis(trimethylsiloxy)cyclohexane (4),[7a,8] the result of carbon-silicon bond cleavage with protonation (protiodesilylation); see Table I.

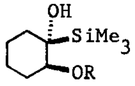
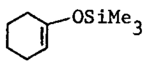
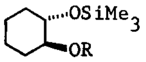
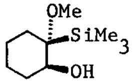
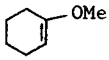
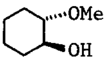
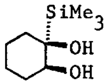
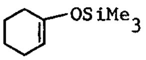
These products could have been formed by pathways involving α- or β-oxidosilanes (see Scheme I). Attack of either alkoxide at silicon would generate an incipient carbanion (as an intermediate or transition state)[9] which in principle could undergo elimination (leading to 3) or protonation (leading to 4). A proton source would be available if the monoalkoxide were formed initially, or if alkoxide anions were formed slowly.[10]

Scheme I



To isolate the α- and β-oxidosilane pathways, we have studied similar reactions of compounds 6, 7, and 9, in which one of the hydroxyl groups is protected. Compound 6 (mp 46-47°)[7,11] was prepared from 2 by treatment with Me_3SiCl/pyridine. Reaction of epoxysilane 1 with MeOH and alumina[12] (dioxane, 110°, 56 hr) gave a mixture of compounds 7 and 9 (3:1 ratio)[13] from which

Table I

Starting Material	Conditions	Products[a]			Isolated Yield (%)
					
2 (R = H)	$\longrightarrow$	3	+	4 (R = $SiMe_3$)	
	KH/THF/0°/2 hr[b]	8(3)		91(96)[c]	65
	KH/Et_2O/RT/30 min[b]	7(0)		86(95)[c,d]	74
	NaH/THF/RT/4 hr[b]	0		92(95)[c,e]	70
6 (R = $SiMe_3$)	$\longrightarrow$	3	+	4 (R = $SiMe_3$)	
	KH/THF/RT/30 min[b]	86(91)		14(9)	71
	KH/THF/0°/1.5 hr[b]	46		40[c,f]	-
	NaH/THF/RT/20 hr	0		84[g]	-
7 (R = Me)	$\longrightarrow$	3	+	8 (R = Me)	
	KH/THF/0°/1 hr[b]	72		28	-
	KH/THF/RT/1 hr[b]	78		22	-
					
9	$\longrightarrow$	10	+	11	
	KH/THF/0°/2 hr	(99)		0	74
	NaH/THF/reflux/2 hr	94[h,i]		0	-
	NaH/DMF/RT/1 hr	65		35[i]	-
	KOtBu/tBuOH/reflux/24 hr	35		65[i]	-
					
12	$\longrightarrow$	3			
	KH/THF/0°/45 min[b]	91(96)[j]			69
	NaH/THF/RT/2 hr[b]	91(95)[j]			65

(a) % Purity by VPC. Numbers in parentheses indicate purity after distillation. (b) Me_3SiCl added before (aqueous) workup. (c) The corresponding cis isomer, 5 (see footnote 8), was demonstrated to be absent by VPC analysis. (d) Remainder believed to be 6. (e) Remainder believed to be the monotrimethylsilyl ether of cyclohexanediol. (f) Remainder believed to be bis-silylated starting material. (g) Remainder is starting material. (h) Remainder is unidentified. (i) Solvent also present. (j) Remainder believed to be cyclohexanone and solvent.

7[7a] was isolated by chromatography on Florisil. Compound 9 was prepared from reaction of 1 with MeOH containing CF_3CO_2H as previously reported.[6]

The reactions of compounds 6, 7, and 9 with base are summarized in Table I. With compounds 6 and 7, only the α-alkoxide route is possible, and formation of the silyl enol ether 3 might be expected, especially if deprotonation of the OH is fast relative to protonation of the incipient α-siloxycarbanion. When compounds 6 and 7 were treated with KH in THF, followed by Me_3SiCl, the silyl enol ether 3 was formed as the major product, but compounds 4 and 8,[7a,14] respectively, were also formed. When compound 6 was treated with NaH/THF (expected to deprotonate the OH more slowly than does KH), followed by Me_3SiCl, compound 4 was produced as the only product in a slow reaction. (Treatment of 2 with NaH/THF followed by Me_3SiCl also produced 4.)[16] In the base treatment of compound 9, only the β-alkoxide route is possible. Treatment of 9 with KH/THF cleanly produced the normal β-elimination product 1-methoxycyclohexene (10). When compound 9 was treated with NaH/THF, the reaction was considerably slower, but 10 was again produced. Treatment of 9 with NaH/DMF[6b] or with KOtBu/tBuOH produced mixtures of 1-methoxycyclohexene (10) and trans-2-methoxycyclohexanol (11)[7a,15] (the product expected from protonation). Thus, products of elimination can be formed by both α- and β-oxidosilane pathways,[17] and products of protonation can be formed by both pathways if a proton source is present.[18]

As mentioned above, base-induced reactions of α,β-dihydroxysilanes may in principle involve either α- or β-oxidosilanes. The fact that treatment of 2 (in which a trans antiparallel relationship between the Me_3Si and the β-OH groups is not possible) with KH followed by Me_3SiCl yields predominantly a product derived from protonation, while similar treatment of acyclic α,β-dihydroxysilanes[2] (in which such a trans antiparallel relationship is possible) yields only products of elimination, suggests that the α-alkoxide route can compete with the β-alkoxide route, and that it takes place preferentially by an anti pathway.[19]

To provide further evidence on the stereochemistry of these reactions, we have prepared the α,β-dihydroxysilane 12[20] in which the Me_3Si and β-OH groups are trans. When this compound was treated with KH/THF, followed by Me_3SiCl, only silyl enol ether 3 was formed,[22] in marked contrast to the corresponding reaction of the isomeric compound 2 (which gave mostly 4). Even the use of NaH in this reaction yielded only 2, with no trace of either 4 or 5.[8] These reactions must be taking place by the α-oxidosilane pathway, and in an anti manner.

This work, together with that of the preceding communication,[2] demonstrates that the base-induced elimination reactions of α-oxidosilanes with a β-leaving group take place preferentially by an anti pathway. Moreover, when this favorable geometry is impossible, protiodesilylation can compete unless proton sources are absent. Synthetic applications of these reactions are envisioned.[23]

References and Notes

1. On leave from University of Agricultural Sciences, Bangalore-560065, India.
2. P. F. Hudrlik, R. H. Schwartz, and A. K. Kulkarni, preceding communication.
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5. P. F. Hudrlik, D. Peterson, and R. J. Rona, J. Org. Chem., 40, 2263 (1975); P. F. Hudrlik and D. Peterson, J. Am. Chem. Soc., 97, 1464 (1975).
6. (a) P. F. Hudrlik, J. P. Arcoleo, R. H. Schwartz, R. N. Misra, and R. J. Rona, Tetrahedron Lett., 591 (1977); see also (b) C. M. Robbins and G. H. Whitham, Chem. Commun., 697 (1976).
7. Satisfactory (a) IR, NMR, mass spectra, and (b) elemental analysis were obtained.
8. Authentic samples of the silyl ether 4 and of the corresponding cis isomer 5 were prepared by Me_3SiCl/pyridine treatment of trans- and cis-1,2-cyclohexanediol respectively. Compounds 4 and 5 have been previously reported: (a) T. Nishishita, M. Yoshihara, and S. Oshima, Shitsuryo Bunseki, 20, 347 (1972); Chem Abstr., 78, 83483u (1973); (b) Z. Lasocki, Syn. Inorg. Metal-Org. Chem., 3, 29 (1973); Chem Abstr., 78, 97756x (1973); (c) V. Prey and N. Kubadinow, Liebigs Ann. Chem., 701, 40 (1967).

9. The postulated conversions are shown in a stepwise manner for clarity. The stereospecificity of β-elimination reactions of β-oxidosilanes,[5] and the results described here, suggest that in systems having geometry suitable for facile elimination reactions, carbanions having an appreciable lifetime are not generally involved (where a carbanion-stabilizing group is not present).

10. An attempt to generate the dianion using $(Me_3Si)_2NK$ in THF did not significantly improve the results.

11. The structure assigned to 6 is based on the assumption that silylation takes place at the less hindered hydroxyl.

12. The procedure is adapted from that of G. H. Posner and D. Z. Rogers, J. Am. Chem. Soc., 99, 8208 (1977).

13. A similar mixture of 7 and 9 was prepared from 2 by treatment with MeLi followed by MeI.

14. A comparison sample of 8 was prepared by treatment of trans-2-methoxycyclohexanol (11)[15] with Me_3SiCl/pyridine. Compound 8 (stereochemistry unspecified) has been reported.[8c]

15. A comparison sample of trans-2-methoxycyclohexanol (11) was prepared by the reported procedure (S. Winstein and R. B. Henderson, J. Am. Chem. Soc., 65, 2196 (1943)).

16. When the reactions of 2 with KH/THF and with NaH/THF were quenched with water rather than Me_3SiCl, 4 was again found to be the major isolated product, although in lower yields; trans-1,2-cyclohexane diol was isolated from the aqueous layers from workup. Thus, not surprisingly, silicon-oxygen transfers take place readily.

17. A few examples of elimination processes involving α-oxidosilanes with a β-leaving group have been reported (see footnote 16 in preceding communication[2]).

18. The base-induced cleavage of carbon-silicon bonds in α-hydroxysilanes (resulting in protiodesilylation) is well known (the Brook rearrangement, see refs cited in ref 2) and has been shown to proceed with inversion of configuration at carbon (A. G. Brook, Accounts Chem. Res., 7, 77-84 (1974)). Base-induced protiodesilylation of β-hydroxysilanes has previously been observed in compounds in which the Me_3Si group is attached to a double bond (T. H. Chan and W. Mychajlowskij, Tetrahedron Lett., 3479 (1974); B. B. Snider, M. Karras, and R. S. E. Conn, J. Am. Chem. Soc., 100, 4624 (1978)) or an epoxide ring (T. H. Chan, P. W. K. Lau, and M. P. Li, Tetrahedron Lett., 2667 (1976)); retention of configuration has been observed in both cases. In our early attempts to prepare enol ethers from α,β-epoxysilanes (see ref 3), we found that the reaction of 1-trimethylsilyl-1-octene epoxide with NaOMe/MeOH (presumably generating a β-hydroxysilane) resulted in the formation of 1-methoxy-2-octanol along with the expected β-hydroxysilane (R. J. Rona, Ph.D. Thesis, Rutgers University, New Brunswick, New Jersey, 1978). It is interesting to note that the reaction 2 → 4 (and 6 → 4) proceeds with retention of configuration. However, since 4 is presumably the more stable isomer (and we have not yet observed a cleavage product from the stereoisomer 12), a definitive statement about the stereochemistry of the process cannot be made.

19. The fact that elimination products were obtained from 6 and 7 could indicate that a syn pathway is also possible, or that equilibrating carbanion intermediates intervened; in any case it should be noted that products from protonation were also formed in these reactions.

20. The α,β-dihydroxysilane 12 (mp 85-86°)[7] was prepared in 11% yield by treatment of cyclohexenyltrimethylsilane[21] with $KMnO_4$ using the procedure of K. Wiberg and K. A. Saegebarth, J. Am. Chem. Soc., 79, 2822 (1957).

21. A. D. Petrov, V. F. Mironov, and V. G. Glukhovtsev, Zh. Obshch. Khim., 27, 1535 (1957); Chem. Abstr., 52, 3668h (1958).

22. When 12 was treated with KH/ether (at 0° for 1 hr) followed by quenching with aqueous $NaHCO_3$ (without adding Me_3SiCl), silyl enol ether 3 was again formed, as 95% of the product mixture (along with 5% of cyclohexanone).

23. We thank the National Science Foundation (CHE77-10523) and the National Institutes of Health (CA-23037) for their support of this work, and we thank Robert J. Rona for carrying out a preliminary experiment.

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