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NUCLEOPHILIC SUBSTITUTION AT SILICON: INFLUENCE OF THE NATURE OF THE LEAVING GROUP ON THE STEREOCHEMISTRY

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Summary

The stereochemistries observed for nucleophilic substitutions on optically active bromo- and thiophenyl-silanes are compared with those reported for Cl, F, OR and H leaving groups. They allow the completion of the previously proposed empirical order for the dependence of stereochemistry in the nature of the leaving group viz.; predominant stereochemistry: IN → RN; ease of substitution: Br ≃ Cl >> SR ≃ F >> OMe > H.

Most studies of the mechanism of nucleophilic substitutions at silicon have have been performed with Cl, F, OR and H as leaving groups [1—5]. Such reactions are stereoselective occuring either with inversion or retention. The stereochemical outcome appears to depend primarily on the nature of the leaving group [6,7]. Because of this great importance of the lability of the Si—X bond for the stereochemistry, we were interested in optically active R_3SiBr and R_3SiSR compounds which have been much less investigated. A few studies have been reported, especially substitutions by nucleophiles such as $LiAlH_4$, MeOH, H_2O and ROM [7,8].

Results and discussion

(1) Si—Br as leaving group

The (—) α-naphthylphenyl neopentylsilane was chosen as a representative model for bromosilanes. Because of their great sensitivity to racemization [9] the bulky neopentyl group was required to avoid a loss of optical purity under the reaction conditions. This compound was prepared by bromination of the corresponding optically active silane, the absolute configuration of which is known [10]: this reaction occurs with retention [7]. The results are summarized in Table 1. The predominant stereochemistry is determined by chemical correlations (Scheme 1).

Inversion of configuration is the common stereochemical outcome for reac-

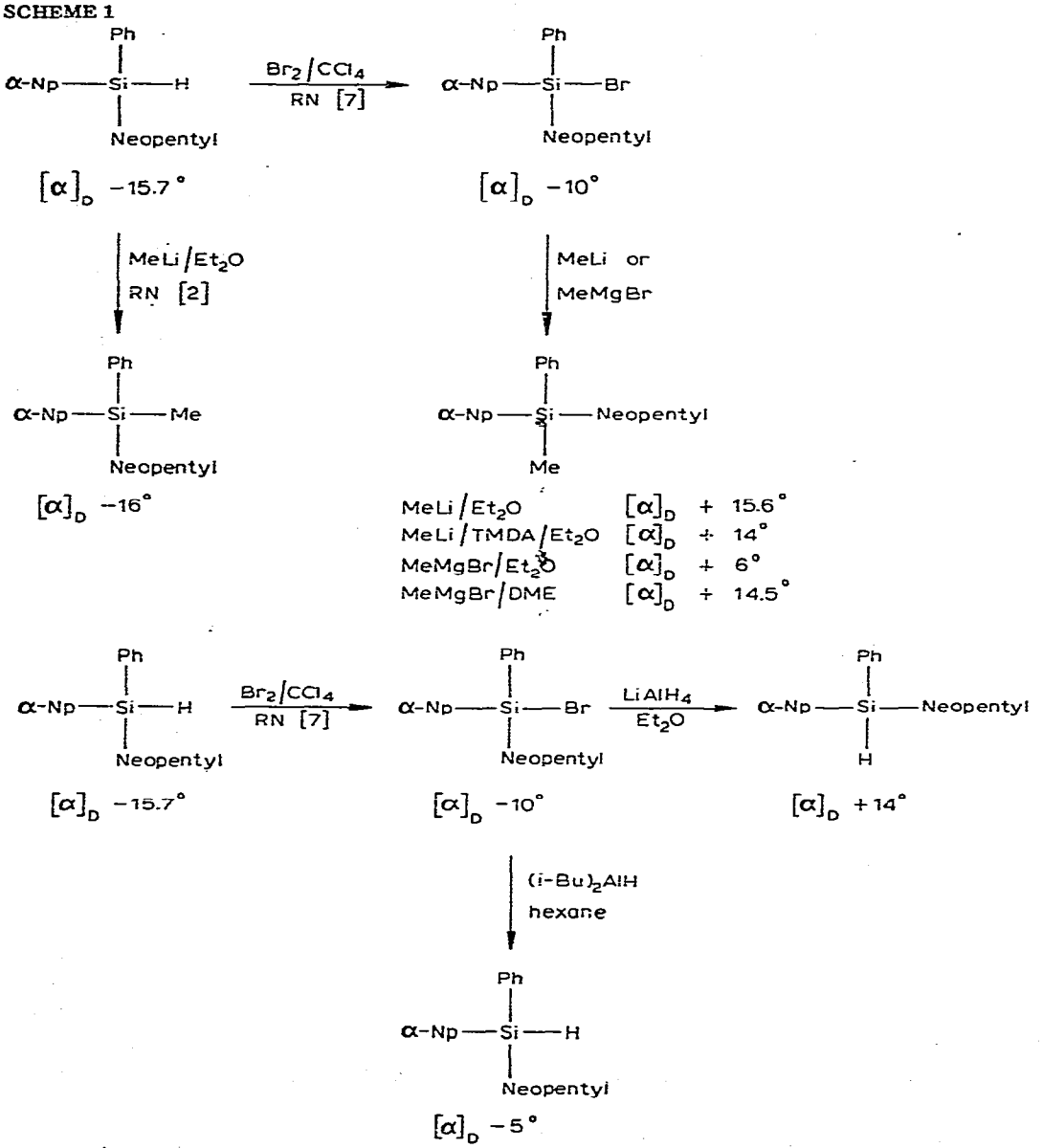
TABLE 1

(—) $R_3SiBr + R'M \rightarrow R_3SiR' + MBr$

Run no.	Reagents[a]	Products R_3SiR'		Predominant stereochemistry[b]
1	$MeLi/Et_2O$	R_3SiMe	$[\alpha]_D$ +15.6°	IN
2	$MeLi/TMDA/Et_2O$	R_3SiMe	$[\alpha]_D$ +14°	IN
3	$MeMgBr/Et_2O$	R_3SiMe	$[\alpha]_D$ +6°	IN
4	MeMgBr/DME	R_3SiMe	$[\alpha]_D$ +14.5°	IN
5	$LiAlH_4/Et_2O$	R_3SiH	$[\alpha]_D$ +14°	IN
6	$(i\text{-}Bu)_2AlH$/hexane	R_3SiH	$[\alpha]_D$ −5°	RN

[a] DME, dimethoxyethane; TMDA, tetramethylethylenediamine. [b] See Scheme 1.

SCHEME 1

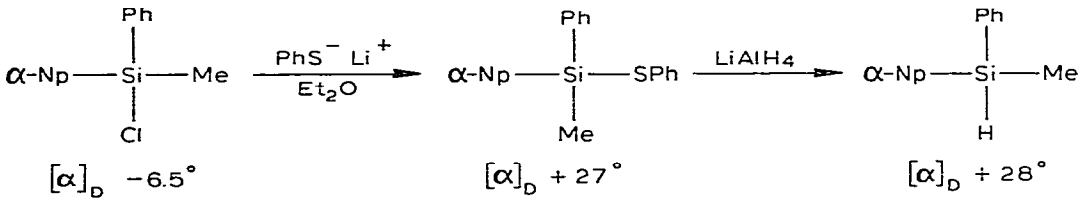


tions of (—) R_3SiBr with alkylorganolithiums or Grignard reagents (runs 1, 2, 3, 4); solvation of the Li^+ cation (TMDA, run 2) or of the magnesium atom (run 4 with DME) does not effect the stereochemistry. Reduction by $LiAlH_4$ in ether leads to inversion, while $(i\text{-}Bu)_2AlH$ in hexane solvent is the only reagent which gives predominant retention. There are (1) a low stereoselectivity (run 6), and (2) and a great decrease in the reduction rate compared to that in reactions of a Si—OMe or Si—F bond. The stereochemical behaviour is quite similar for R_3SiBr and R_3SiCl; they undergo inversion with the same reagents [6], and retention only with $(iBu)_2AlH$ [11]. However this last reaction occurs at a Si—Br bond slowly and with a lower stereoselectivity.

(2) Thiophenyl leaving group

The thiophenyl leaving group was used in the stereochemical study of the silicon—sulphur bond. The corresponding α-naphthylphenylmethylthiophenylsilane was prepared by reaction of (—) R_3SiCl with PhS^-Li^+ in ether solvent. $LiAlH_4$ reduction of the (+) thiophenylsilane in ether leads to the (+) α-naphthylphenylmethylsilane (Scheme 2):

SCHEME 2



The (—) chlorosilane and the (+) R_3SiH have the same configuration. Assuming inversion for reaction with $LiAlH_4$ [11], the inversion of configuration can be assigned by Scheme 2 for the reaction of PhSLi on the Si—Cl bond. Table 2 shows the stereochemical results for reactions with organometallic reagents and aluminohydrides.

TABLE 2

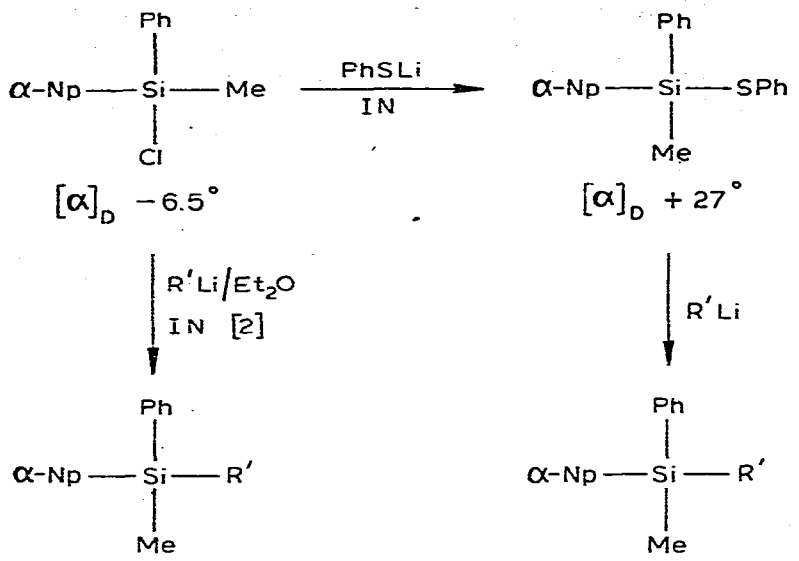
(+) R_3SiSPh [a] + $R'M \rightarrow R_3SiR'$ [b] ($R'M$ = R'Li, R'MgX, $LiAlH_4$ or $(i\text{-}Bu)_2AlH$; R_3Si = α-NpPhMeSi)

Run no.	Reagents	Products R_3SiR'		Predominant stereochemistry [d]
1	EtLi	R_3SiEt	$[\alpha]_D$ −5° [c]	92% RN
2	n-BuLi	R_3Si-n-Bu	$[\alpha]_D$ +0.8°	65% RN
3	Allyl Li	R_3Siallyl	$[\alpha]_D$ +7°	75% IN
4	$PhCH_2Li$	R_3SiCH_2Ph	$[\alpha]_D$ +4.7°	85% IN
5	EtMgBr	R_3SiEt	$[\alpha]_D$ +6° [c]	95% IN
6	n-BuMgBr	R_3Si-n-Bu	$[\alpha]_D$ −1.2°	70% IN
7	Allyl MgBr	R_3Siallyl	$[\alpha]_D$ +10°	90% IN
8 PhCH	$PhCH_2MgBr$	R_3SiCH_2Ph	$[\alpha]_D$ +5.5°	90% IN
9	$LiAlH_4$	R_3SiH	$[\alpha]_D$ +27°	90% IN
10	$(i\text{-}Bu)_2AlH$/hexane	R_3SiH	$[\alpha]_D$ −30°	95% RN

[a] The (+) R_3SiSPh is a liquid at room temperature. After several recristallizations at −40°C, its optical activity was unchanged and we obtained a maximum $[\alpha]_D$ of +27°, so we assume an optical purity of ca. 100%. [b] The absolute configuration and maximum $[\alpha]_D$ of all R_3SiR' derivatives are known [2]. [c] These results are from ref. 12. [d] See Schemes 3 and 4.

The predominant stereochemistry is determined by chemical correlations (Schemes 3 and 4).

SCHEME 3. R'Li with R' = Et, n-Bu



R' = Et $[\alpha]_D$ −6.2°

R' = n-Bu $[\alpha]_D$ +1°

R' = Et $[\alpha]_D$ −5°

R' = n-Bu $[\alpha]_D$ +0.8°

Reactions of alkyllithiums and $(i\text{-Bu})_2AlH$ with (+) α-naphthyl phenyl methyl thiophenyl silane lead to retention of configuration (runs 1, 2): however, charge delocalized allyl or benzyl organolithiums give inversion (runs 3, 4). The $LiAlH_4$ reduction (run 9) and coupling reactions with Grignard reagents lead to inversion. These results and those reported for the α-NpPhMeSiSMe derivative [8] indicate that the stereochemical outcomes of reactions of silicon—sulphur and silicon—fluoride bonds are similar: the fluorosilane undergoes displacement of the fluoride group by $LiAlH_4$ with inversion, by alkyllithiums with retention, and by Grignard reagents or charge-delocalized organolithiums with inversion.

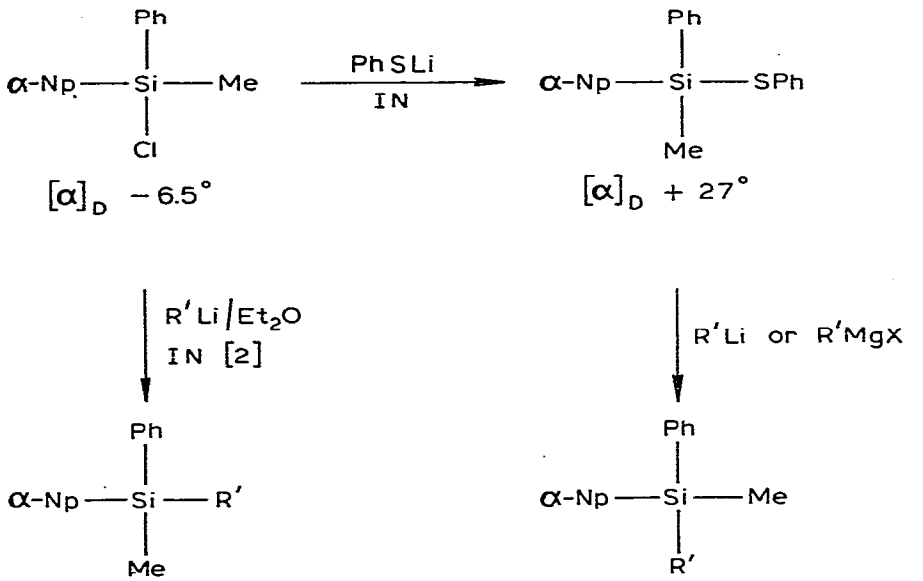
These results, taken with those reported previously [3—6] allow us to give the following empirical order for the stereochemical outcomes accompanying changes in nature of the leaving group:

Predominant stereochemistry: IN → RN

Lability of the leaving group: Br ≃ Cl >> SR ≃ F >> OMe > H

The differences between bromide and chloride or between SR and fluoride leaving groups are small. This shows clearly that the changes of stereochemistry cannot be correlated with physical properties of the leaving group such as the polarisability [13] or the pK_a of the conjugate acid [6]: for instance F or SR groups which have very different physical characteristics are very similar as leaving groups.

SCHEME 4. R'Li with R' = allyl or benzyl; R'MgX with R' = Et, n-Bu, allyl or benzyl.



R' = Et	$[\alpha]_D$	−6.5°	R'Li = allylLi	$[\alpha]_D$	+ 7°
R' = n-Bu	$[\alpha]_D$	+1°	R'Li = $PhCH_2Li$	$[\alpha]_D$	+ 4.7°
R' = allyl	$[\alpha]_D$	−12.8°	R'MgX = EtMgBr	$[\alpha]_D$	+ 6°
R' = benzyl	$[\alpha]_D$	−6.9°	R'MgX = n-BuMgBr	$[\alpha]_D$	− 1.2°
			R'MgX = allyl MgBr	$[\alpha]_D$	+ 10°
			R'MgX = $PhCH_2MgCl$	$[\alpha]_D$	+ 5.5°

Experimental

Materials

The preparation of (+) α-NpPhMeSiSPh was described previously [12].

Preparation of the (—) α-NpPh-n-pentSiBr. The bromination of the (—) α-NpPh-n-pentSiH was carried out as described by Sommer et al. [7]. A solution of bromine in CCl_4 was added dropwise to a solution of (—) α-NpPh-n-pentSiH [8], $[\alpha]_D$ −15.7° (*c* 10, pentane) in anhydrous CCl_4, kept at 0°C under N_2. The solvent was removed under vacuum and the (—) α-NpPh-n-pentSiBr was recovered as an oil, $[\alpha]_D$ −10° (*c* 10, pentane). RMN (δ, ppm): 8—7 (12 H, m); 1.4, H (2 H, s); 0.9 (9 H, s). Anal. Found: C, 65.68; H, 6.19; Br, 20.72; Si, 7.51. $C_{21}H_{23}BrSi$ calcd.: C, 65.79; H, 6.00; Br, 20.88; Si, 7.31%.

Preparation of the (—) α-NpPh-n-pentSiMe. Treatment of a solution of (—) α-Np Ph-n-pent Si-H (200 mg, 0.66 mmol) with MeLi (1.4 *N*, 5 ml) in ether for 24 h at reflux temperature gave α-NpPh-n-pentSiMe. After hydrolysis (HCl 10%) and chromatography on silica gel with pentane/benzene (90/10), (+) α-NpPhn-

pentSiMe was obtained in 82% yield with $[\alpha]_D$ —16° (*c* 9, pentane). RMN (δ, ppm): 8—7 (12 H, m); 1.3 (2 H, s); 0.9 (9 H, s); 0.6 (3 H, s). Anal. Found: C, 83.54; H, 8.09; Si, 8.85. $C_{22}H_{26}Si$: C, 83.01; H, 8.17; Si, 8.80.

Reactions. General procedure

All reactions were carried out under nitrogen. An excess of the organometallic reagent was usually added to the silane in anhydrous diethyl ether and the mixture was hydrolysed with acid (10% HCl). The silanes obtained were purified by preparative TLC (silica gel PF 254) using benzene/pentane (10/90) as eluant and identified by physical constants. The $[\alpha]_D$ values were measured with a Perkin—Elmer 151 polarimeter.

(1) Reactions with (—) α-NpPh-n-PentSiBr ($[\alpha]_D$ —10° (c 10, pentane)

Run no. 1: treatment of (—) α-NpPh-n-pentSiBr (0.5 mmol) with a MeLi solution (1.4 *N*, 3 ml) in ether solvent for 12 h, gave α-NpPh-n-pentSiMe. Chromatography over silica gel with pentane/benzene (90/10) gave (+) α-NpPh-n-pentSiMe, $[\alpha]_D$ +15.6° (*c* 10, pentane).

Run no. 2: to a solution of MeLi (1.4 *N*, 5 mmol) and TMDA (5.5 mmol) in ether as solvent was added a solution of (—) α-NpPh-n-pentSiBr (0.5 mmol). By a procedure similar to that above, (+) α-NpPh-n-pentSiMe with $[\alpha]_D$ +14° (*c* 9, pentane), was obtained.

Run no. 3: treatment of (—) α-NpPh-n-pentSiBr (0.5 mmol) with MeMgBr (1.1 *N*, 5 ml) in ether solvent for 24 h at reflux temperature gave (+) α-NpPh n-pentSiMe with $[\alpha]_D$ +6° (*c* 10, pentane).

Run no. 4: to a solution of MeMgBr in ether (1.1 *N*, 8 ml) was added 20 ml of DME. The ether solvent was evaporated under vacuum. $MgBr_2$ precipitated in the medium and the supernatant solution was separated ($Mg(Me)_2$ in DME). Treatment of (—) α-NpPh-n-pentSiBr (0.5 mmol) in DME with this solution for 12 h at room temperature, gave (+) α-NpPh-n-pentSiMe with $[\alpha]_D$ +14.4° (*c* 10, pentane).

Run no. 5: to a solution of $LiAlH_4$ in dry ether (2 *N*, 3 ml) was added a solution of (—) α-NpPh-n-pentSiBr (0.5 mmol) in ether. After hydrolysis and chromatography over silica gel (pentane/benzene 90/10) of the crude product, (+) α-NpPh-n-pentSiH was recovered with $[\alpha]_D$ + 14° (*c* 8, pentane).

Run no. 6: treatment of (—) α-NpPh-n-pentSiBr (0.5 mmol) with $(i\text{-Bu})_2AlH$ (1 mmol) in hexane solvent for 72 h at reflux temperature gave (—) α-NpPh-n-pentSiH in 40% yield with $[\alpha]_D$ —5° (*c* 12, pentane).

(2) Reactions with (+) α-NpPhMeSiSPh ($[\alpha]_D$ +27° (c 12, pentane))

Runs no. 1 and 5: These results were reported previously [12].

Run no. 2: treatment of (+) α-NpPhMeSiSPh (0.5 mmol) with n-BuLi (0.9 *N*, 2 ml) in ether solvent for 3 h, at room temperature gave (+) α-NpPhMeSi-n-Bu with $[\alpha]_D$ +0.8° (*c* 10, pentane).

Run no. 3: treatment of (+) α-NpPhMeSiSPh (0.5 mmol) with allyllithium (0.5 *N*, 2 ml prepared by Seyferth's procedure [14]) in ether solvent for 24 h at room temperature gave (+) α-NpPhMeSi$CH_2CH{=}CH_2$ with $[\alpha]_D$ + 7° (*c* 12, pentane).

Run no. 4: treatment of (+) α-NpPhMeSiSPh (0.5 mmol) with $PhCH_2Li$ (0.3 *N*, 4 ml, prepared by cleavage of the dibenzyl ether) in ether solvent for 24 h at room temperature, gave (+) α-NpPhMeSiCH_2Ph with $[\alpha]_D$ +4.7° (*c* 10, pentane).

Run no. 6: treatment of (+) α-NpPhMeSiSPh (0.5 mmol) with n-BuMgBr (1.2 *N*, 5 ml) in ether solvent for 5 h at reflux temperature, gave (—) α-NpPhMeSi-n-Bu with $[\alpha]_D$ —1.2° (*c* 14, pentane).

Run no. 7: treatment of (+) α-NpPhMeSiSPh (0.5 mmol) with allylMgBr (1.1 *N*, 5 ml) in ether solvent for 24 h at reflux temperature, gave (+) α-NpPhMeSiCH_2CH=CH_2 with $[\alpha]_D$ +10° (*c* 15, pentane).

Run no. 8: treatment of (+) α-NpPhMeSiSPh (0.5 mmol) with $PhCH_2MgBr$ (1.05 *N*, 5 ml) in ether solvent for 24 h at reflux temperature, gave (+) α-NpPhMeSiCH_2Ph with $[\alpha]_D$ +5.5° (*c* 10, pentane).

Run no. 9: to a solution of $LiAlH_4$ in dry ether (2 *N*, 6 ml) was added a solution (+) α-NpPhMeSiSPh (0.5 mmol) in ether; after hydrolysis and chromatography over silica gel (pentane/benzene 90/10) of the crude product, (+) α-NpPhMeSiH was recovered with $[\alpha]_D$ +27° (*c* 11, pentane).

Run no. 10: treatment of (+) α-NpPhMeSiSPh (0.5 mmol) with $(i\text{-Bu})_2AlH$ (2 mmol) in hexane solvent for 10 h at reflux temperature gave (—) α-NpPh. MeSiH with $[\alpha]_D$ —30° (*c* 10, pentane).

References

1 R. Corriu and B. Henner, J. Organometal. Chem., 102 (1975) 407.
2 L.H. Sommer, Stereochemistry, Mechanism and Silicon, McGraw-Hill New-York, 1965.
3 (a) R. Corriu and G. Royo, J. Organometal. Chem., 40 (1972) 229; (b) R. Corriu and G. Royo, Bull. Soc. Chim. Fr., 1497 (1972).
4 (a) R. Corriu and J. Masse, J. Chem. Soc. Chem. Commun., 1373 (1968); (b) R. Corriu and J. Masse, J. Organometal. Chem., 34 (1972) 221; (c) R. Corriu and J. Masse, J. Organometal. Chem., 25 (1972) 51.
5 R. Corriu, C. Guérin and J. Masse, J. Chem. Res., (1977) 1877.
6 L.H. Sommer, Intra-science Chem. Rept., 7 (1973) 1.
7 L.H. Sommer, G.A. Parker, N.C. Lloyd, C.L. Frye and K.W. Michael, J. Amer. Chem. Soc., 89 (1967) 857.
8 L.H. Sommer and J. McLick, J. Amer. Chem. Soc., 89 (1967) 5806.
9 R. Corriu and M. Henner, J. Organometal. Chem., 74 (1974) 1.
10 R. Corriu, G. Lanneau and M. Leard, J. Organometal. Chem., 64 (1974) 79.
11 L.H. Sommer, J. McLick and C.M. Golino, J. Amer. Chem. Soc., 94 (1972) 669.
12 R. Corriu and C. Guérin J. Organometal. Chem., 144 (1978) 165.
13 L.H. Sommer, Stereochemistry, Mechanism and Silicon, McGraw-Hill, New-York, 1963, p. 28; A.I Vogel, W.T. Cresswell and J. Leicester, J. Phys. Chem., 58 (1954) 174.
14 D. Seyferth and M.A. Weiner, J. Org. Chem., 26 (1961) 4797.