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# A $^{13}C$ and $^{6}Li$ NMR study of the lithiation of some silyl ethers in hydrocarbon solvents by t-butyllithium

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## Abstract

Methoxytrimethylsilane and methoxymethyltrimethylsilane are metallated at the silyl methyl position by t-butyllithium in cyclopentane in a facile and high yield reaction to give the corresponding α-lithio silanes. Under these conditions, competition from substitution reactions at the silicon center is virtually non-existent. At low temperatures a transient, methoxytrimethylsilane coordinated t-butyllithium dimer is observed and characterized by $^{13}C$ and $^{6}Li$ NMR. Under similar conditions, trimethylchlorosilane and tetramethylsilane show no signs of interaction or reaction with the alkyllithium reagent.

## Introduction

The ability of alkyllithium compounds to metallate saturated organosilicon compounds to yield α-lithio silanes was first recognized by Peterson in 1967 [1]. He reported the successful metallation of both tetramethylsilane and n-butyltrimethylsilane by a 1/1 mixture of n-butyllithium and tetramethylethylenediamine (TMEDA). The reaction times were three to four days and the yields 36 to 46%. In another study [2], West et al. found that t-butyllithium in the presence of TMEDA gave similar yields from tetramethylsilane under similar conditions. They also found that silanes bearing substituents susceptible to nucleophilic attack, such as chloride and alkoxide, could by metallated. However, substitution at silicon by the t-butyl group was competitive. All reactions were run in the presence of either TMEDA or tetrahydrofuran (THF). In 1970 Frye et al. reported [3] the metallations of two siloxanes in hydrocarbon solvent in the absence of any additional Lewis bases. The yields were surprisingly good and competition from cleavage reactions was not a problem under these conditions. More recent work has shown that methoxymethyl-

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trimethylsilane can be readily metallated in THF by sec-butyl- [4] and t-butyllithium [5], while n-butyllithium gives only the substitution product [5]. Interestingly, t-butyllithium metallates at a methyl group while sec-butyllithium metallates at the methylene position.

It appears that the metallation of tetraalkylsilanes requires the use of strongly coordinating Lewis bases and extended reaction times to achieve even moderate yields. The metallation of silanes bearing potential leaving groups is easier to achieve,. but requires the use of sterically hindered alkyllithium compounds. Even then, cleavage reactions remain a serious problem. While the presence of added Lewis bases or coordinating solvents may enhance the metallation of silanes, it greatly increases the rate of substitution at silicon. This problem has hampered the development of high yield routes to many α-lithio silanes [6].

Our group has been interested in the interaction and reaction of ethers with alkyllithium compounds. We have recently shown that t-butyllithium and diethyl ether exist in a dynamic, temperature-dependent equilibrium between tetra-solvated dimers and unsolvated tetramers, with the dimers favored at low temperatures [7]. We also showed that the dimer is the reactive species in the reaction between diethyl ether and t-butyllithium at −80 °C. These results suggested to us that the previous success of other workers in metallating silanes bearing either ether or silyl ether type functionalities might be due to precoordination of the silanes to the alkyllithium compounds.

We report here that methoxytrimethylsilane and methoxymethyltrimethylsilane can be metallated regiospecifically and in high yield by t-butyllithium in cyclopentane in the absence of any additional Lewis bases. At low temperatures and without additional Lewis bases, substitution reactions at silicon are virtually non-existent. We also present $^{13}C$ and $^{6}Li$ NMR data for (1) the coordination complex between methoxytrimethylsilane and t-butyllithium, (2) intermediate mixed aggregates, and (3) the final alkyllithium products.

Our approach to the study of these reactions was to employ $^{6}Li$ enriched t-butyllithium and to observe the reactions which ensue on addition of the silanes at low temperatures by a combination of $^{6}Li$ and $^{13}C$ NMR spectroscopy. The determination of alkyllithium aggregate size is often discernible from the multiplicity of the α-carbon resonance due to $^{13}C-^{6}Li$ coupling.

## Results and discussions

Shown in Fig. 1 is the $^{13}C$ NMR spectrum of t-butyllithium (95% $^{6}Li$) in cyclopentane at −90 °C to which has been added one equivalent of methoxytrimethylsilane. There are new peaks at 50.0, 35.0, and −1.6 ppm (integration ratio of 2/3/6) and a five-line multiplet at 12.9 ppm, in addition to peaks for the uncoordinated t-butyllithium tetramers. The five-line multiplet at 12.9 ppm has a peak separation of 7.8 Hz and relative peak intensities of 1/2/3/2/1. The peak intensities correspond to those predicted for a $^{13}C$ nucleus coupled to two equivalent $^{6}Li$ nuclei ($I = 1$), while the $^{13}C-^{6}Li$ coupling of 7.8 Hz is nearly identical to the coupling observed for t-butyllithium dimers in diethyl ether [7,8] and other dimers in coordinating solvents [9]. Based on these observations and the relative intensities of the peaks, we assign these new resonances to a coordinated t-butyl-

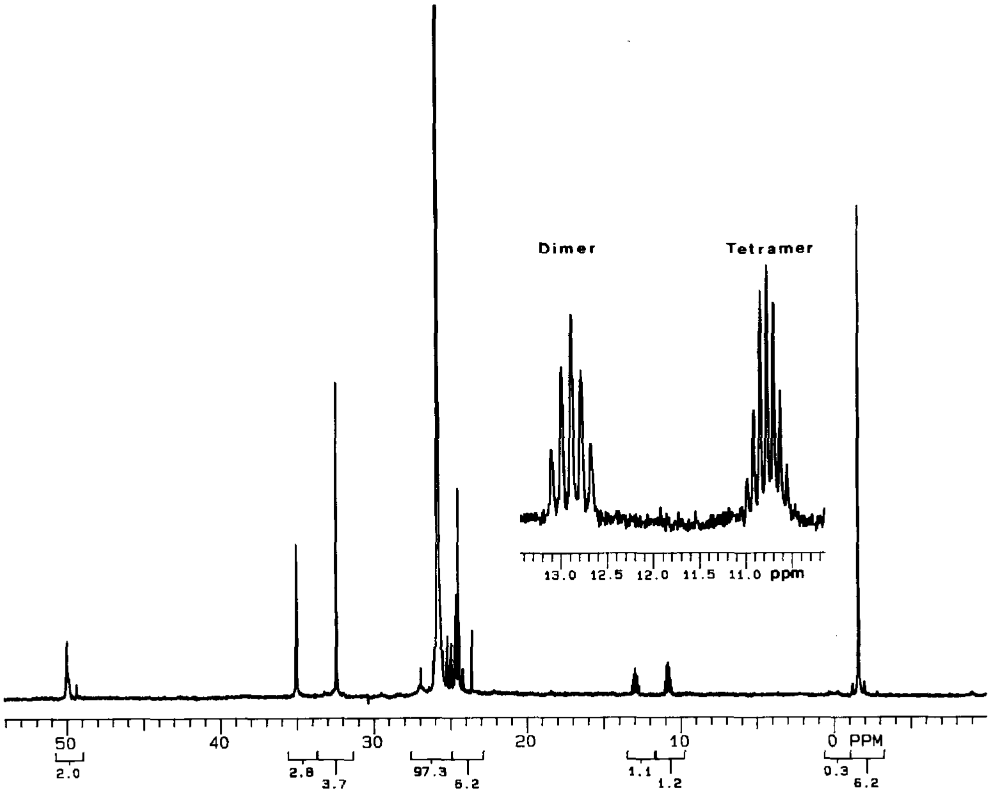
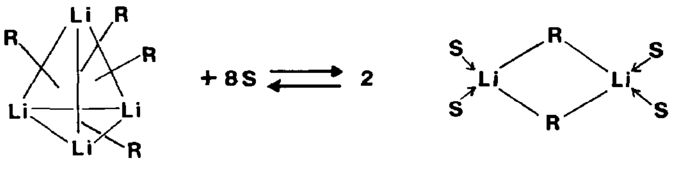


Fig. 1. 75 MHz $^{13}$C NMR spectrum of a mixture of $(t\text{-Bu}^6\text{Li}\cdot 2\text{O(Me)SiMe}_3)_2$ and $(t\text{-Bu}^6\text{Li})_4$ in cyclopentane at −90 ° C. [t-BuLi] = 0.88 *F*, [MeOSiMe$_3$] = 0.88 *M*. The α-carbon region is shown in the inset. Other peak assignments are listed in Table 1.

lithium dimer, $[t\text{-BuLi}\cdot 2\text{O(Me)SiMe}_3]_2$ (I) formed by reaction of eight silyl ethers with a t-butyllithium tetramer:



(1)

R = t-Bu, S = MeOSiMe$_3$

Further support for the coordinated dimer comes from the $^6$Li spectra. There is a new resonance 0.28 ppm downfield from the uncoordinated t-butyllithium tetramer peak which slowly increases in intensity at the expense of the tetramer peak. The final ratio of the peaks for t-butyllithium tetramer to dimer approaches 1/1 [10 *] at −90 ° C, as expected for an O/Li ratio of 1/1. In contrast to the rapid formation of

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* Reference number with asterisk indicates a note in the list of references.

Table 1

$^{13}C$ Chemical shifts and $^{13}C-^{6}Li$ coupling constants (in parentheses) for selected reactants and products

| | Compound [a] | t-butyl groups | | MeOSiMe$_3$ or MeOCH$_2$SiMe$_3$ | | | |
|---|---|---|---|---|---|---|---|
| | | $CH_3$ | quartenary | $CH_3O$- | $CH_3Si$- | Li-$CH_2Si$- | MeO$CH_2Si$- |
| | $(RLi)_4$ | 32.5 [b] | 10.7 (5.45) [c] | | | | |
| I | $(RLi\cdot 2S)_2$ | 35.0 | 12.8 (7.8) | 50.0 | −1.6 | | |
| II | $R'_3RLi_4$ | 32.8 | 9.6 (5.7) | 49.4 | 0.1 | −8.9 (*) [e] | |
| III | $(R'Li)_n$ | | | 51.4 | 0.0 | −7.6 (*) [e] | |
| V | $(R''Li)_4$ | | | 62.8 | 1.0 | −10.7 (4.6) | 72.2 |
| | RH | 23.5 | 24.5 | | | | |
| | R'H | | | 49.3 [d] | −1.5 [d] | | |
| | R''H | | | 62.7 | −3.8 | | 66.8 |

[a] R = t-butyl; S = methoxytrimethylsilane; R' = $CH_2SiMe_2OMe$; R'' = $CH_2SiMe_2CH_2OMe$. [b] Chemical shifts are in ppm relative to TMS by assigning cyclopentane to 25.8 ppm. [c] $^{13}C-^{6}Li$ coupling in Hz. [d] Determined from a separate experiment without RLi. [e] Peaks were broad, but no $^{13}C-^{6}Li$ coupling was observed.

diethyl ether coordinated dimers [7], the methoxytrimethylsilane coordinated dimers form much more slowly at this temperature. At −60 °C the formation of I is much faster, as is the metallation reaction. At this temperature the equilibrium of eq. 1 still favors the dimer, but does not lie completely to the right [11*].

After 4 or 5 h at −60 °C, or upon warming to −40 °C, I is converted almost exclusively to the metallation product, lithiomethylmethoxydimethylsilane. This is observed first as a mixed tetrameric aggregate with t-butyllithium (II).

$$\underset{(I)}{(t\text{-BuLi}\cdot 2S)_2} \rightarrow \underset{(II)}{[(t\text{-Bu})R_3Li_4]} \qquad (2)$$

$$S = Me_3SiOMe,\ R = CH_2SiMe_2OMe$$

The assignment of the structure of II is based on the new peaks, listed in Table 1, in the $^{13}C$ spectra which grow in at the expense of the dimer peaks. All of these peaks are singlets except for a seven-line multiplet at 9.6 ppm (Fig. 2, inset) associated with the quaternary carbon of the lone t-butyl group of II. This establishes the aggregate as a tetramer. The relative integrations of the new lithiomethylmethoxydimethylsilane signals compared with those of the new t-butyllithium signals establish the 3/1 nature of the aggregate.

As the reaction proceeds at −60 °C, the dimer resonances are depleted faster than the rate of formation of new dimers. New resonances associated with an aggregate of undetermined size, III, consisting only of lithiomethylmethoxydimethylsilane, appear as the t-butyllithium becomes depleted (Fig. 2). The reactivity of the t-butyllithium in the mixed aggregate II is much less than the dimer I. In order to carry the reaction to completion in a reasonable amount of time, it is necessary to warm the reaction mixture. At 25 °C, the mixed aggregate II is converted to the final products within one hour.

$$\underset{(II)}{[(t\text{-Bu})R_3Li_4]} \xrightarrow{\text{slow}} \underset{(III)}{(RLi)_n} \qquad (3)$$

$$R = CH_2SiMe_2OMe$$

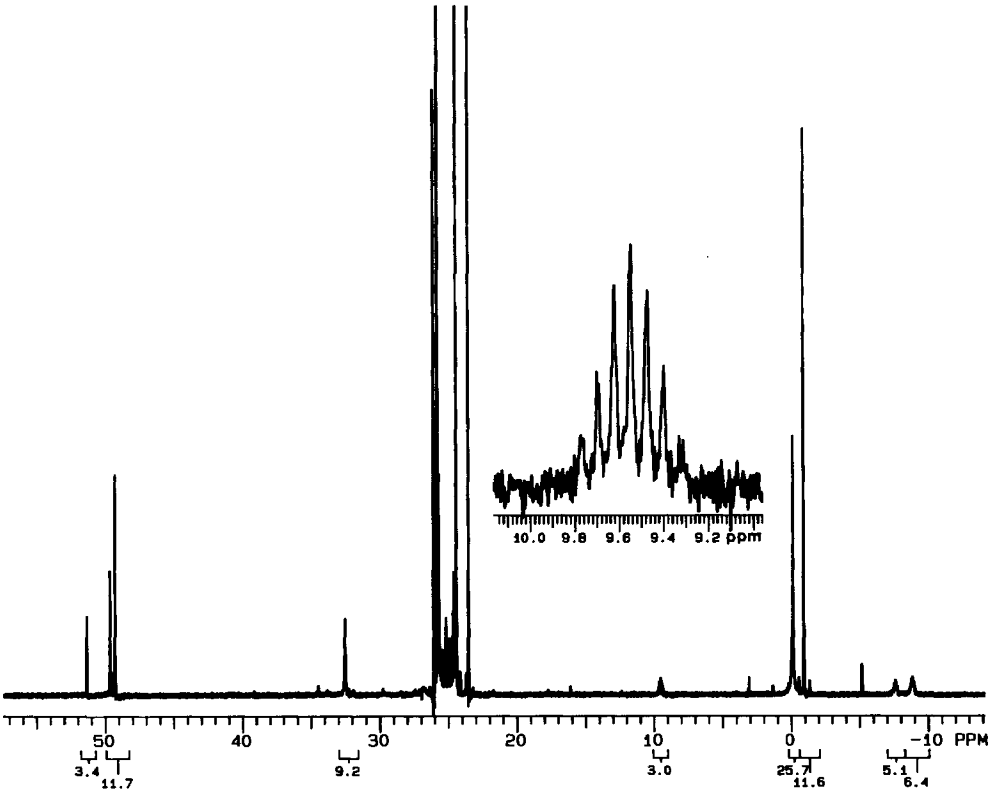

Fig. 2. 75 MHz $^{13}$C NMR spectrum of the reaction mixture from t-Bu$^6$Li and MeOSiMe$_3$ after warming to −40 °C and then recooling to −75 °C. The seven-line $\alpha$-carbon resonance of the t-butyl group from (t-Bu)(CH$_2$SiMe$_2$OMe)$_3$Li$_4$ (II) is shown in the inset.

In addition to peaks associated with III and with a small amount of unreacted methoxytrimethylsilane, there are also very small peaks corresponding to the substitution product, t-butyltrimethylsilane (< 2% by NMR) [12*]. In contrast, this is the major product when the reaction is run in the presence of TMEDA at 25 °C [2].

As expected, when the metallation reaction is run at higher O/Li ratios (8–10) and at − 60 °C, dimer formation is faster. Under these conditions the mixed aggregate II begins to react before the dimer is completely depleted (15–30 min). All of the t-butyllithium reacts within 1 h. Although the rate of formation of I at low O/Li ratios is faster than the formation of II (eq. 2), the rate of formation of dimer is not sufficiently fast to allow for kinetic analysis of the metallation reaction as a function of silane and alkyllithium concentrations. At higher O/Li ratios this problem can be avoided, but the mixed aggregate II becomes competitive with the dimer towards metallation of the alkoxysilane. In our previous work with diethyl ether [7], where dimer depletion is initially first order in dimer and first order in uncomplexed diethyl ether, the coordinated dimer showed no signs of reaction after several hours at − 80 °C for O/Li $\leq$ 2. However, solutions of t-butyllithium/methoxytrimethylsilane begin to react immediately upon mixing for all O/Li ratios studied (1–10).

We have also generated III on a larger scale using commercially available t-butyllithium. A solution of t-butyllithium in pentane was added to a slight excess of methoxytrimethylsilane in cyclopentane and then stirred at −78 °C for 1 h. The reaction mixture was allowed to warm to room temperature and stirred an additional 2 h before quenching with trimethylchlorosilane in THF. The expected product (methoxydimethylsilyl) (trimethylsilyl)methane (IV) was obtained in 63% isolated yield. Although we did not attempt to optimize the conditions for this reaction, it does demonstrate the potential synthetic value of this $\alpha$-lithio alkoxysilane [13*] and confirms its structure.

$$\mathrm{Me_3SiOMe} \xrightarrow[\substack{-78 \rightarrow +25\,^{\circ}\mathrm{C} \\ \text{cyclopentane}}]{\text{t-BuLi}} \underset{\text{(III)}}{(\mathrm{MeOSiMe_2CH_2Li})_n} \xrightarrow[\mathrm{THF}]{\mathrm{Me_3SiCl}} \underset{\text{(IV)}}{\mathrm{MeOSiMe_2CH_2SiMe_3}} \qquad (4)$$

In order to investigate the generality of this type of metallation reaction, we looked at a structurally different type of silyl ether. We found that under the same conditions, methoxymethyltrimethylsilane is metallated by t-butyllithium at a rate comparable to the rate of metallation of methoxytrimethylsilane.

$$\mathrm{MeOCH_2SiMe_3} \xrightarrow[\substack{-78 \rightarrow +25\,^{\circ}\mathrm{C} \\ \text{cyclopentane}}]{\text{t-BuLi}} \underset{\text{(V)}}{(\mathrm{MeOCH_2SiMe_2CH_2Li})_4} \xrightarrow{\mathrm{D_2O}}$$

$$\mathrm{MeOCH_2SiMe_2CH_2D} \qquad (4)$$

Evidence for the formation of a methoxymethyltrimethylsilane/t-butyllithium complex was not obtained and the resonances for uncomplexed t-butyllithium tetramers showed no changes in either chemical shift or $^{13}$C–$^{6}$Li coupling [14]. The fact that a complexed dimer was not observed is assumed to be due to rapid metallation compared to dimer formation. After completion of the reaction, the only metallation product observed was tetrameric lithiomethyldimethylmethoxymethylsilane (V). This was assigned based on the $^{13}$C spectrum (Table 1). The tetrameric aggregation state was determined from the seven-line multiplet, with 4.7 Hz peak separation, for the lithiated carbon at −10.7 ppm.

The position of metallation was further established by GC/MS and $^{13}$C NMR analysis of a sample hydrolyzed with $D_2O$. The $^{13}$C spectrum of the organic layer revealed a 1/1/1 triplet ($^{13}$C–$^{2}$H coupling) 0.25 ppm upfield of the silyl methyl resonance at −3.8 ppm. Integration of the $^{13}$C resonances was consistent with one deuterium per molecule. There was no evidence for deuteration at the methylene carbon, which would have formed from the hydrolysis of lithio(methoxy)(trimethylsilylmethyl)methane (VI).

Lithiation of the silyl methyl group to produce the kinetic product, V, instead of the thermodynamic product VI, has also been observed for this reaction in THF [5]. However, the reason for formation of V remains unclear. We speculate that methoxymethyltrimethylsilane coordinates to t-butyllithium to form a coordinated complex analogous to II. Examination of models suggests that lithiation would be directed to the silyl methyls by "proximity effects" [16], and would inhibit the reaction at the methylene carbon. The details of the mechanism and the possible role of proximity effects are currently under investigation.

Under the same conditions as used in the NMR experiments described for methoxytrimethylsilane, trimethylchlorosilane and tetramethylsilane showed no signs of complexation or metallation between −80 and +20 °C. However, trimethylchlorosilane did undergo a very slow substitution reaction upon warming to room temperature. When tetramethylsilane was added to preformed diethylether/t-butyllithium dimers at −80 °C, there was still no reaction. This is further support for an intramolecular lithiation reaction for coordinated silyl ethers, as suggested above.

While there are apparently no examples of metallation of saturated tetraalkylsilanes by alkyllithium compounds in non-coordinating solvents, there are now several examples for organosilanes containing an ether linkage. The conversions for the latter type of reactions are good to excellent and appear to be regiospecific. Importantly, competition from substitution reactions at silicon is not a problem under these conditions.

## Experimental

All laboratory manipulations involving the synthesis and sample preparation of air-sensitive compounds used for NMR experiments were performed in a high vacuum system or in an argon-filled drybox with recirculating atmosphere through an oxygen scavenger. Cyclopentane, THF, and diethyl ether were dried over $LiAlH_4$ and degassed on the vacuum line. Syringes, NMR tubes, and volumetric glassware used in the NMR experiments were dried, then kept under vacuum overnight in the drybox port prior to use. Methoxytrimethylsilane was prepared as described elsewhere [2a]. Traces of methanol were removed by a final distillation from sodium metal. Samples used for the NMR experiments were also dried over $LiAlH_4$ and degassed on the vacuum line. Methoxymethyltrimethylsilane and natural abundance t-butyllithium in pentane were obtained from Aldrich Chemical Co. The methoxymethyltrimethylsilane was dried over $LiAlH_4$ and degassed on the vacuum line prior to use. Mass spectra were obtained from a Hewlett-Packard 5970A GC/MS and data station.

### *Preparation of t-BuLi*

Halide-free t-$Bu^6Li$ was prepared from bis(t-butyl)mercury and 95.5% isotopically-enriched $^6Li$ metal (U.S. Services) as described earlier [14] and sublimed prior to use.

### *Preparation of NMR samples*

The same basic procedure was followed for the experiments with methoxytrimethylsilane, methoxymethyltrimethylsilane, trimethylchlorosilane, and tetramethylsilane. In a typical experiment, 0.63 g (1.0 mmol) of t-$Bu^6Li$ was weighed out in the drybox and dissolved to 1.0 ml in cyclopentane (8% cyclopentane-$d^{10}$, Wilmad; 92% cyclopentane, 99.9%, Wiley Organics). The solution was transferred to a 5 mm NMR tube and capped with a septum. Outside the drybox, the septum was wrapped with parafilm and the NMR tube cooled in a dry ice/acetone bath. The sample was then placed in the pre-cooled probe of the NMR spectrometer and a control spectrum was run to determine the purity of the sample prior to further use. Only samples with $\leq 2.0\%$ $(t\text{-}Bu)_3(t\text{-}BuO)Li_4$, as determined by integration of the $^6Li$ spectrum [14], were used. The appropriate silane was then added by gas-tight syringe and the sample mixed well with cooling. Samples with high O/Li ratios were prepared similarly, except that the t-Bu$^6$Li solution was added via gas-tight syringe to the pre-cooled alkoxysilane.

*Reaction of lithiomethyldimethylmethoxymethylsilane (III) with trimethylchlorosilane*

In an oven-dried, three-neck round bottom flask under an argon atmosphere, 29.4 ml of 1.7 *M* solution of t-BuLi in pentane (50 mmol) was added slowly via syringe to a stirred solution of 5.73 g (55 mmol) of methoxytrimethylsilane. The dry ice bath was allowed to warm slowly over a period of 3 h before being removed. The mixture was then stirred an additional 2 h. A solution of 8.24 ml (65 mmol) of trimethylchlorosilane in 3.5 ml of THF was then added very slowly to the reaction mixture while cooling in an ice bath. A white precipitate formed immediately. After stirring 30 min at room temperature, an anhydrous work-up was performed. Fractional distillation produced 5.5 g of (methoxydimethylsilyl)(trimethylsilyl)methane (IV) (63% yield). b.p. 150–152°C (lit. 148–152°C). MS: $m/z$ (relative intensity); 161 (100, $P-15$); 131 (81); 73 (30); 59 (51).

*Deuteration of lithiomethyldimethylmethoxymethylsilane (V)*

An NMR sample prepared from equimolar amounts of methoxymethyltrimethylsilane and t-Bu$^6$Li was opened and carefully hydrolyzed with $D_2O$ after warming to room temperature. The $^{13}$C spectrum of the organic layer revealed a 1/1/1 triplet ($^{13}$C–$^2$H coupling) 0.25 ppm upfield of the silyl methyl resonance at $-3.8$ ppm. Integration of the $^{13}$C resonances was consistent with one deuterium per molecule.

*NMR parameters and conditions*

All NMR spectra were obtained on a Varian VXR-300 NMR spectrometer at 75 and 44 MHz for $^{13}$C and $^6$Li, respectively. Typical conditions for $^{13}$C NMR were 18° flip angle, 2.857 s repetition rate, 17,500 Hz spectra width, 32k transform, 128–1024 transients, Waltz proton decoupling. All chemical shifts were set relative to TMS by setting the resonance for protonated cyclopentane to 25.8 ppm.

Typical conditions for $^6$Li spectra were one transient, 90 degree flip angle, 300 Hz spectral width, and 32k transform. Spectra were run with gated proton decoupling such that there was proton decoupling but no NOE. All $^6$Li chemical shifts are relative to (t-Bu$^6$Li)$_4$ at 0.00 ppm.

The temperature within the NMR probe was determined from the difference in the $^1$H chemical shifts of methanol peaks using the algorithm supplied by the NMR manufacturer. Decoupling power was kept to a minimum to avoid heating of the sample.

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## References

1 D.J. Peterson, J. Organomet. Chem., 9 (1967) 373.
2 (a) G.A. Gornowicz and R. West, J. Am. Chem. Soc., 90 (1968) 4478. (b) R. West and G.A. Gornowicz, J. Organomet. Chem., 28 (1971) 25.

3 C.L. Frye, R.M. Salinger, F.W.G. Fearon, J.M. Klowsowski and T. De Young, J. Org. Chem., 35 (1970) 1308.
4 P. Magnus and R. Glenn, Organometallics, 1 (1982) 553.
5 F.A. Carey and A.S. Court, J. Org. Chem., 37 (1972) 939.
6 For leading references concerning the generation and uses of alpha-lithio silanes see: E.W. Colvin, Silicon in Organic Synthesis, Butterworths, London, 1981.
7 T.F. Bates, M.T. Clarke and R.D. Thomas, J. Am. Chem. Soc., 110 (1988) 5109.
8 W. Bauer, W.R. Winchester and P. v. R. Schleyer, Organometallics, 6 (1987) 2371.
9 (a) PhLi, 8 Hz: G. Fraenkel, H. Hsu and B.M. Su, in R.O. Bach (Ed.), Lithium, Current Applications in Science, Medicine and Technology, Wiley, New York, 1985, p. 273; (b) n-BuLi, 7.8 Hz: D. Seebach, R. Hassig and J. Gabriel, Helv. Chim. Acta, 66 (1983) 2269.
10 After 4 h at $-90\,^\circ$C, the ratio of peaks in the $^6$Li NMR spectra for dimer to tetramer was 45/55. There were additional peaks at $-0.22$ and $-0.01$ ppm, in a ratio of 3/1, due to II. These additional peaks accounted for about 5% of the total peak integration.
11 As with the diethyl ether/t-butyllithium system, tetrasolvated dimers are favored over unsolvated tetramers at low temperatures due to the large and negative $\Delta S$ term in the Gibbs free-energy equation. See ref. 7.
12 Alkoxysilane/alkyllithium complexes, such as described here, have been theorized to account for the retention of configuration observed for nucleophilic substitution reactions involving alkoxysilanes and alkyllithium compounds: L.H. Sommer, Stereochemistry, Mechanism and Silicon, McGraw-Hill, New York, 1965, pp. 59–61.
13 An alternate two-step synthesis, starting with trimethylsilylmethyl magnesium chloride, gave IV in 34% overall yield: S. Bain, S. Ijadi-Maghsoodi and T.J. Barton, J. Am. Chem. Soc., 110 (1988) 2611.
14 R.D. Thomas, M.T. Clarke and R.M. Jensen, Organometallics, 5 (1986) 1851.
15 D. Seyferth and E.G. Rochow, J. Org. Chem., 20 (1955) 250.
16 P. Beak and A.I. Meyers, Acc. Chem. Res., 19 (1986) 356.