Synthetic Methods

DOI: 10.1002/ange.201003174

# Acceleration of the Substitution of Silanes with Grignard Reagents by Using either LiCl or $YCl_3$/MeLi[**]

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Silanes are the primary source for a variety of organosilicon compounds and frequently appear as intermediates in organic synthesis.[1] Attachment of a carbon chain to silanes is one of the most fundamental derivatizations, but thus far one-step methods are limited and rely mostly on the hydrosilylation of olefins and acetylenes.[1b,c,2] If the direct substitution of the hydride of a silane using an organometallic compound, such as a Grignard reagent, is viable, then this would be an alternative method for the above process; however, this approach has not been adopted because of the low leaving ability of the hydride towards substitution.[3] Herein we show that the practical substitution of silanes with Grignard reagents is possible in the presence of LiCl[4] as formulated in Equation (1).[5]

$$\underset{(1\ \text{equiv})}{R_nSiH_{4-n}} + R'MgX \xrightarrow[\text{THF}]{\text{LiCl}} R_nH_{3-n}Si\text{-}R' \qquad (1)$$

The impressive effect of the lithium salt upon the substitution of a silane is highlighted below. In 1959, Gilman et al. reported that triphenylsilane and benzyl Grignard reagent in boiling THF gave triphenyl(benzyl)silane (**1**) in 53% yield after 4 days.[3a] This is consistent with our observation that a similar reaction for a shortened period of 8 hours yielded only a small amount of **1** [Eq. (2)]. However, the addition of LiCl to this system nicely accelerated the substitution, depending on its quantities, to give **1** in good yield [Eqs. (3) and (4)].

$$\underset{(1\ \text{equiv})}{Ph_3SiH} + \underset{(3\ \text{equiv})}{PhCH_2MgCl} \begin{cases} \xrightarrow[\text{THF, reflux, 8 h}]{} \underset{\mathbf{1}\ \ 13\%}{Ph_3Si(CH_2Ph)} & (2)\\ \xrightarrow[\text{THF, reflux, 8 h}]{\text{LiCl (0.3 equiv)}} 37\% & (3)\\ \xrightarrow[\text{THF, reflux, 8 h}]{\text{LiCl (1 equiv)}} 80\% & (4) \end{cases}$$

Additional examples are shown in Equations (5) and (6). Whereas methyl(phenyl)silane was not alkylated with benzylmagnesium bromide at room temperature, its alkylation readily proceeded in the presence of LiCl to give **2** in excellent yield [Eq. (5); hereafter yields in parentheses refer to those determined by $^1$H NMR analysis using trichloroethylene as an internal standard]. The quantity of LiCl could be reduced to 5 mol% without considerable decrease in the product yield. Although diphenylsilane is more reactive towards Grignard reagents, the LiCl-induced acceleration itself is still notable when the reaction is carried out at a low temperature [Eq. (6)]. This fast alkylation finds application even at low temperature in the double benzylation of phenylsilane with excess Grignard reagent, and results in delivering the trisubstituted silane **3** [Eq. (7)]. The acceleration was also notable for the alkylsilane **4**, which after reacting gave **5** [Eq. (8)], even though the silane **4** is intrinsically less reactive than its aryl counterpart, $PhSiH_3$.[6]

$$\underset{(1\ \text{equiv})}{Ph(Me)SiH_2} + \underset{(1\ \text{equiv})}{PhCH_2MgBr} \xrightarrow[\text{THF, r.t., 4 h}]{\text{LiCl}} \underset{\mathbf{2}}{Ph(Me)HSi(CH_2Ph)} \qquad (5)$$

$$\begin{array}{lll} \text{LiCl} & \text{(1 equiv)} & 77\% \\ & \text{(0.05 equiv)} & 80\% \\ \text{none} & & (\ 3\%) \end{array}$$

$$\underset{(1\ \text{equiv})}{Ph_2SiH_2} + \underset{(1\ \text{equiv})}{PhCH_2MgBr} \xrightarrow[\text{THF, -30 °C, 1 h}]{\text{LiCl}} Ph_2HSi(CH_2Ph) \qquad (6)$$

$$\begin{array}{lll} \text{LiCl} & \text{(1 equiv)} & 74\% \\ \text{none} & & 7\% \end{array}$$

$$\underset{(1\ \text{equiv})}{PhSiH_3} + \underset{(3\ \text{equiv})}{PhCH_2MgCl} \xrightarrow[\text{THF, -78 °C, 2 h}]{\text{LiCl}} \underset{\mathbf{3}}{PhHSi(CH_2Ph)_2} \qquad (7)$$

$$\begin{array}{lll} \text{LiCl} & \text{(1 equiv)} & 97\% \\ \text{none} & & 10\% \\ & & (PhH_2Si(CH_2Ph)\ 66\%) \end{array}$$

$$\underset{\substack{\mathbf{4}\\(1\ \text{equiv})}}{C_{18}H_{37}SiH_3} + \underset{(3\ \text{equiv})}{PhCH_2MgCl} \xrightarrow[\text{THF, reflux, 4 h}]{\text{LiCl}} \underset{\mathbf{5}}{C_{18}H_{37}SiH_2(CH_2Ph)} \qquad (8)$$

$$\begin{array}{lll} \text{LiCl} & \text{(1 equiv)} & 80\%\ \text{(quant.)} \\ \text{none} & & (64\%) \end{array}$$

The above acceleration is also valid for allyl or aryl Grignard reagents. The results of allylation are shown in Table 1, wherein using LiCl in either a stoichiometric amount or an amount as low as 5 mol% resulted in good product yields.[7] The absence of LiCl resulted in poor product yields.

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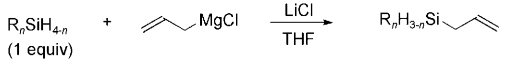
[**] This work was supported by The Kurata Memorial Hitachi Science and Technology Foundation and a Grant-in-Aid for Scientific Research on Priority Area (No.16073208) from the Ministry of Education, Culture, Sports, Science, and Technology (Japan).

Supporting information for this article is available on the WWW under http://dx.doi.org/10.1002/anie.201003174.

***Table 1:*** The LiCl acceleration of the allylation of silanes.



| Entry | $R_nSiH_{4-n}$ | Allyl-MgCl [equiv] | LiCl [equiv] | $T$ [°C] | $t$ [h] | Yield [%][a] |
|---|---|---|---|---|---|---|
| 1 | $Ph_3SiH$ | 2 | 1 | reflux | 4 | 93 (96) |
| 2 | | 2 | 0.3 | reflux | 4 | (70) |
| 3 | | 2 | 0.05 | reflux | 4 | (64) |
| 4 | | 2 | none | reflux | 4 | (16) |
| 5 | $PhMeSiH_2$ | 1 | 1 | RT | 1 | 81 |
| 6 | | 1 | 0.3 | RT | 1 | 80 |
| 7 | | 1 | 0.05 | RT | 1 | 86 |
| 8 | | 1 | none | RT | 1 | 20 |
| 9 | $Ph_2SiH_2$ | 1 | 1 | −78 | 4 | 92 (quant.) |
| 10 | | 1 | 0.3 | −78 | 4 | (81) |
| 11 | | 1 | 0.05 | −78 | 4 | (75) |
| 12 | | 1 | none | −78 | 4 | (13) |

[a] Yields of isolated products. Yields in parentheses were determined by $^1$H NMR analysis using an internal standard (trichloroethylene).

In general, the results shown in Table 1 are similar to those of the benzylation reactions depicted in Equations (2)–(6). The advantage of using LiCl was also observed for the arylation of silanes (Tables 2 and 3).[8]

The practical advantage of LiCl-promoted arylation lies in the reaction of substrates that are intrinsically unreactive at or above room temperature (Table 2 and Table 3, entries 3–5). A more interesting case is shown in Equation (9), wherein the introduction of a mesityl group to $PhSiH_3$ gives **6** in an excellent yield.

***Table 2:*** The LiCl acceleration of the arylation of $Ph(Me)SiH_2$.

$$\underset{\text{(1 equiv)}}{Ph(Me)SiH_2} + ArMgBr \xrightarrow[\text{THF, 50 °C}]{\text{LiCl (1 equiv)}} Ph(Me)HSi\text{-}Ar$$

| Entry | Ar (equiv) | $t$ [h] | Yield [%][a] LiCl | No LiCl |
|---|---|---|---|---|
| 1 | Ph (1.25) | 2 | 57 (63) | (32) |
| 2 | $p$-$FC_6H_4$ (1) | 8 | 67 (70) | (18) |
| 3 | $o$-$(MeO)C_6H_4$ (1.25) | 4 | 81 (96) | (47) |

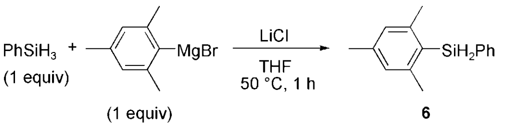
[a] Yields of isolated product are based on silane. Yields in parentheses were determined by $^1$H NMR analysis using an internal standard (trichloroethylene).

***Table 3:*** The LiCl acceleration of the arylation of $PhSiH_3$.

$$\underset{\text{(1 equiv)}}{PhSiH_3} + \underset{\text{(1.25 equiv)}}{ArMgBr} \xrightarrow[\text{THF}]{\text{LiCl}} PhH_2Si\text{-}Ar$$

| Entry | Ar | LiCl [equiv] | $T$ [°C] | $t$ [h] | Yield [%][a] LiCl | No LiCl |
|---|---|---|---|---|---|---|
| 1 | Ph | 1 | −60 | 1 | 72 (75) | (7) |
| 2 | $o$-$(MeO)C_6H_4$ | 1 | −20 | 2 | 84 (93) | 53 |
| 3 | 1-naphthyl | 1 | 0 | 2 | 81 (80) | (2) |
| 4 | $o$-$MeC_6H_4$ | 1 | 0 | 2 | 85 (98) | (27) |
| 5 | $o$-$MeC_6H_4$ | 0.3 | 0 | 2 | 97 (quant.) | (27) |

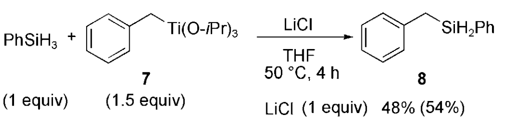
[a] Yields of isolated product are based on silane. Yields in parentheses are those determined by $^1$H NMR analysis using an internal standard (trichloroethylene).



(9)

| | | |
|---|---|---|
| LiCl | (1 equiv) | 80% (91%) |
| LiCl | (0.3 equiv) | 84% (93%) |
| none | | (8%) |

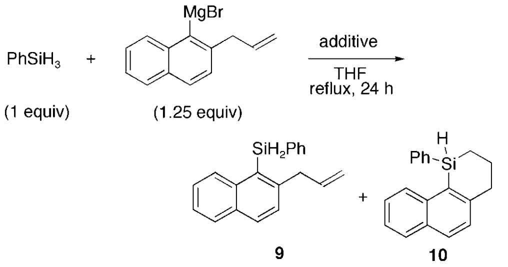
The LiCl-induced acceleration described above is not limited to Grignard reagents. For example, the benzyltitanium reagent **7**, prepared in situ from equimolar amounts of $PhCH_2MgCl$ and $Ti(O\textit{i}Pr)_4$,[9] is almost inert to $PhSiH_3$, but the addition of LiCl to this mixture promoted the reaction to give **8** in a better yield [Eq. (10)].



(10)

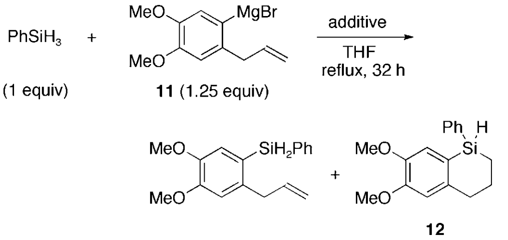
| | | |
|---|---|---|
| LiCl | (1 equiv) | 48% (54%) |
| none | | ( 2%) |

Another aspect of the lithium effect is that it can be used with other metal catalysis, and this is illustrated by the reagent system of $YCl_3$ and MeLi.[10] Although $PhSiH_3$ and 2-allyl-1-naphthyl Grignard reagent gave only a small amount of **9**, even under forcing conditions, the presence of $YCl_3$/MeLi [11] promoted the substitution to give the transient product **9** in greater than 65 % yield; and **9** eventually underwent yttrium-catalyzed intramolecular hydrosilylation[12] to give cyclic silane **10** in good overall yield [Eq. (11)]. Obviously, the metathesis between MeLi and $YCl_3$ generated LiCl in situ as well as an active yttrium catalyst. Similarly, the $YCl_3$/MeLi catalyst enabled the preparation of **12** from $PhSiH_3$ and **11** in one pot [Eq. (12)].[13,14]



(11)

| additive | 9 | 10 |
|---|---|---|
| none | (3%) | none |
| $YCl_3$/MeLi (1:0.6) (0.3 equiv) | 7% | 58% |



(12)

| additive | | 12 |
|---|---|---|
| none | 17% | none |
| $YCl_3$/MeLi (1:0.6) (0.3 equiv) | < trace | 65% |

In summary, substitution of silanes with Grignard reagents is accelerated by the presence of either stoichiometric amounts or catalytic amounts of LiCl. The new cooperative effect of lithium and yttrium derived from the combination of YCl$_3$ and MeLi has led to the one-pot substitution/intramolecular hydrosilylation sequence of a silane and *o*-allylaryl Grignard reagents.

## Experimental Section

Preparation of Ph(Me)HSi(CH$_2$CH=CH$_2$) with 0.05 equiv LiCl (Table 1, entry 7): Allylmagnesium chloride (2.0 M in THF, 0.500 mL, 1.00 mmol) and methylphenylsilane (0.139 mL, 1.00 mmol) were added to a suspension of LiCl (2.1 mg, 0.050 mmol) in 1.0 mL of THF at room temperature under argon. After the reaction mixture had been stirred at room temperature for 1 h, the reaction was terminated by the addition of an aqueous solution of NH$_4$Cl (0.5 mL). The resulting heterogeneous mixture was filtered through Celite, which was rinsed with diethyl ether. The organic phase was dried over Na$_2$SO$_4$ and concentrated in vacuo to give a crude oil, which was chromatographed on silica gel (eluent: hexanes) to afford the title compound (139 mg, 86%) as a colorless oil. The product was fully characterized by $^1$H and $^{13}$C NMR, IR, and elemental analyses.

Received: May 26, 2010
Revised: July 26, 2010

**Keywords:** lithium · magnesium · silanes · synthetic methods · yttrium

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[6] (*tert*-Alkyl)silanes such as ($t$Bu)$_2$SiH$_2$ and ($t$Bu)Ph$_2$SiH did not react with benzyl Grignard reagent even under the LiCl catalysis.

[7] Nickel-catalyzed allylation of trialkylsilanes with Grignard reagent was described in the following literature, which mentions 1) that other metals such as Co, Fe, Cu, Zr, and Ti are less or not active, 2) that benzylation and arylation are not susceptible to the acceleration, and 3) there are no applications starting with mono- or disubstituted silanes. R. J. P. Corriu, J. P. R. Massé, B. Meunier, *J. Organomet. Chem.* **1973**, *55*, 73–84.

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[10] For a recently reported Y-mediated reaction, see: R. Tanaka, H. Sanjiki, H. Urabe, *J. Am. Chem. Soc.* **2008**, *130*, 2904–2905.

[11] The undesirable transfer of the Me group to the silane could be suppressed by adjusting the YCl$_3$/MeLi ratio from 1:1 to 1:0.6 and its quantity from stoichiometric to catalytic (0.3 equiv) amounts.

[12] For yttrium-catalyzed intermolecular hydrosilylation of olefins, see: a) G. A. Molander, E. D. Dowdy, B. C. Noll, *Organometallics* **1998**, *17*, 3754–3758; b) G. A. Molander, E. E. Knight, *J. Org. Chem.* **1998**, *63*, 7009–7012, and references therein. In contrast to the better designed Y catalysts utilized in the above precedents, the simpler YCl$_3$/MeLi combination is not a good catalyst for intermolecular hydrosilylation of olefins, as an attempted silylation of 1-decene with phenylsilane with this catalyst afforded no more than a trace amount of decyl(phenyl)silane. This result indicates that the reactions of Equations (11) and (12) should consist of the first substitution of silane with Grignard reagent, followed by intramolecular hydrosilylation, as described in the text.

[13] Whereas intramolecular hydrosilylation of similar (4-pentenyl)silanes under Pt, Rh, or Co catalysis preferentially affords 5-membered products through 5-*exo-trig* cyclization, the 6-*endo-trig* fashion under Y catalysis as can be seen in Equations (11) and (12) has not been reported; a) H. Sakurai, T. Hirose, A. Hosomi, *J. Organomet. Chem.* **1975**, *86*, 197–203; b) J. V. Swisher, H.-H. Chen, *J. Organomet. Chem.* **1974**, *69*, 83–91. For a relevant 5-*endo-trig* cyclization of (3-butenyl)silane, see: c) G. A. Molander, C. P. Corrette, *Organometallics* **1998**, *17*, 5504–5512.

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