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LETTERS

Carbamoylsilanes from the in situ metalation–silylation of a formamide

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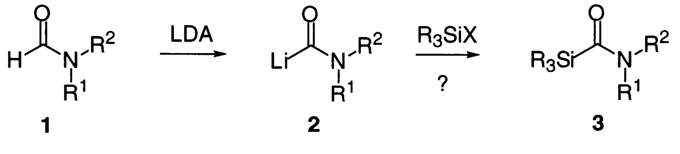
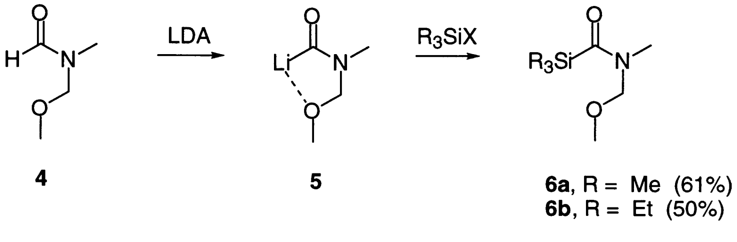
Abstract—In situ treatment (−78°C) of *N*-methoxymethyl–*N*-methylformamide and chlorotrimethylsilane with LDA affords synthetically useful yields of the carbamoylsilane. The latter undergoes silyl group exchange at 145°C in the presence of a chlorosilane and CsF. © 2001 Elsevier Science Ltd. All rights reserved.

Although known for over 30 years, carbamoylsilanes **3** have remained a chemical curiosity because of their relative inaccessibility. The first report of these species was that of Peddle, who combined a bissilyl sulfide and a bis(carbamoyl)mercury, but gave no yield for **3**.[1] A second representative was prepared by Baldwin from the reaction of *t*-$BuPh_2SiLi$ and cyclohexyl isocyanate,[2] but we have been unable to extend this approach.[3] More recently, Murai has employed a hindered *N*-aryl *N*-methyl carbamoyl anion (in the form of a mixed cuprate) plus a silyl halide,[4] or the 1,2-rearrangement (Si/Li) of *N*-silyl–*N*-aryl carbamoyllithiums, to afford carbamoylsilanes.[5] Only the last of these approaches has been used to prepare more than one member of this class of compounds (in yields of 17–40%), and 2,6-disubstitution on the *N*-aryl group is critical to success. These carbamoyllithiums have been prepared by the carbonylation of a lithiated secondary aniline, and it has been stated that no carbamoylsilanes result from the attempted silylation of similarly prepared *N*,*N*-dialkylcarbamoyllithiums.[6]

Conceptually, the most direct access to carbamoylsilanes would stem from the metalation–silylation of *N*,*N*-disubstituted formamides **1**, and several examples of this metalation behavior are known.[7–11] To our knowledge, however, no successful silylation of the carbamoyllithiums **2** thus generated has been reported. We anticipated that, because of its potential for chelation, at least one such reported[9] carbamoyllithium **5** might have a longer lifetime than other options and would thus make the best candidate for in situ silylative





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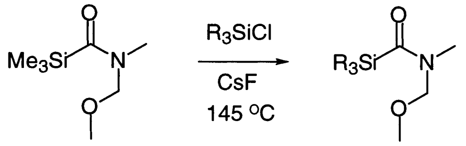
trapping. In the event, slow addition of a THF solution of LDA (−78°C) to a mixture of chlorotrimethylsilane and **4** in THF at −78°C afforded a 61% yield of **6a** after an anhydrous workup.[12] Attempts to extend this approach to the synthesis of higher homologues by employing chlorotriethylsilane were immediately foiled, as complex mixtures containing only small amounts of **6b** were obtained. Although substitution of cyanotriethylsilane as trapping agent[13] resulted in a much cleaner product which contained **6b** in approximately 50% yield, it was inseparable from admixed siloxane ($Et_3SiOSiEt_3$, 2:1 ratio).[14] No carbamoylsilane was detected in the crude product mixture when tBuMe$_2$SiCN or tBuMe$_2$SiOTf were used as potential trapping agents.



6a

6b, R = Et (84%)
6c, R = tBuMe$_2$ (54%)
6d, R = PhMe$_2$ (67%)

In as much as **6a** was now readily available, the possibility of using it as a template for the formation of **6b**–**6d** was examined. Our impetus for exploring this approach came from the knowledge that acylsilanes have served as acyl anion equivalents in the presence of fluoride ion[15] and that KF catalyzes the exchange of silyl groups between a chlorosilane and cyanotrimethylsilane.[16] Thus, heating a mixture of **6a** and the appropriate chlorosilane at 145°C with a catalytic amount (15–20 mole%) of cesium fluoride led to the production of **6b**–**6d** in 54–84% yields.[17] All the carbamoylsilanes displayed the low frequency carbonyl absorption characteristic of these species, as well as the low field location of the carbonyl carbon[12] (cf. corresponding values for **4** of 1687 cm^{-1} and δ 162).

A determination of the relative molar extinction coefficients for the carbonyl infrared absorptions of **4** versus **6a** showed that the former is 5.25 times as large as the latter, a hitherto unrealized difference in this property. All carbamoylsilanes displayed dual ^{1}H and ^{13}C NMR spectra due to the two possible amide rotamers, whose presence in each case was in an approximate ratio of 1:3. The coalescence temperature of the **6a** rotamers was determined to be 75±5°C (methylene protons, 500 MHz, toluene-d_8).

Carbamoylsilane **3** (R = Me, R^1 = R^2 = Et) has been reported to react completely with water in 0.5 h to give the desilylated formamide,[1] while more hindered species survived aqueous workup.[2,4,5] In the present instance, a sample of **6a** in wet DCCl$_3$ was determined to have $t_{1/2} \cong 5$ h by ^{1}H NMR spectroscopy, but in practice, anhydrous conditions were maintained in the manipulation of **6**, as small amounts of desilylated products were difficult to remove (**6a** or **6b** were found to be unstable to glpc or chromatography on silica gel or florisil). We will report shortly on the novel chemistry of these carbamoylsilanes.

*Characterization data for **6b** and **6c***

6b: IR 1584 cm^{-1}; ^{1}H NMR (500 MHz, C$_6$H$_6$): δ 4.43 (s, 2H), 3.02 (s, 3H), 2.93 (s, 3H), 1.1 (m, 9H), 0.88 (q, 6H) (major rotamer); 4.86 (s, 2H), 3.24 (s, 3H), 2.77 (s, 3H), 1.1 (m, 9H), 0.83 (q, 6H) (minor rotamer). ^{13}C NMR (126 MHz, C$_6$H$_6$): δ 186.9, 80.9, 54.3, 30.5, 7.4, 4.1 (major rotamer); 186.5, 74.5, 55.3, 32.3, 7.4, 3.9 (minor rotamer). Methyl peaks of both rotamers at δ 7.4 are believed to be coincident. Anal. calcd for $C_{10}H_{23}NO_2Si$: C, 55.25; H, 10.67; N, 6.44. Found: C, 55.21; H, 10.92; N, 6.49.

6c: IR 1581 cm^{-1}; ^{1}H NMR (500 MHz, C$_6$H$_6$): δ 4.40 (s, 2H), 2.98 (s, 3H), 2.94 (s, 3H), 1.14 (s, 9H), 0.35 (s, 6H) (major rotamer); 4.85 (s, 2H), 3.25 (s, 3H), 2.74 (s, 3H), 1.12 (s, 9H), 0.29 (s, 6H). ^{13}C NMR (126 Hz, C$_6$H$_6$): δ 187.0, 81.0, 54.3, 30.8, 26.7, 17.0, −4.18 (major rotamer); 186.7, 74.7, 55.4, 33.0, 26.7, 25.8, −4.22. t-Butyl protons of both rotamers at δ 26.7 are believed to be coincident. Anal. calcd for $C_{10}H_{23}NO_2Si$: C, 55.25; H, 10.67; N, 6.44. Found: C, 55.44; H, 10.78; N, 6.54.

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12. A solution of **4** (5.6 g, 54 mmol) and TMSCl (7.5 mL, 6.6 g, 61 mmol) in 50 mL THF was treated dropwise at −78°C with a solution of LDA in 50 mL THF prepared from diisopropylamine (7.7 mL, 5.6 g, 55 mmol) and 22 mL of 2.5N nBuLi (55 mmol) in 50 mL of THF in a jacketed addition funnel at −78°C. After allowing the clear mixture to slowly warm to 25°C, volatiles were removed by rotary evaporation to 10 mmHg using a vacuum pump, and anhydrous pentane (15 mL) added. After stirring for 4 h, the granular white precipitate was removed by filter tube ('M' frit) under argon pressure and the filtrate subjected to kugelrohr distillation (80–90°C, 0.2 mmHg) to remove residual solids. The distillate was then fractionated through a vacuum-jacketed 4-inch vigreux column to afford 5.8 g (61%) of colorless **6a**. IR

1584 cm^{-1}; ^{1}H NMR (500 MHz, C_6H_6): δ 4.41 (s, 2H), 2.99 (s, 3H), 2.92 (s, 3H), 0.33 (s, 9H) (major rotamer); 4.84 (s, 2H), 3.22 (s, 3H), 2.74 (s, 3H), 0.28 (s, 9H) (minor rotamer). ^{13}C NMR (126 MHz, C_6D_6): δ 188.0, 80.9, 54.2, 30.7, −1.0 (major rotamer); 187.5, 74.6, 55.2, 32.7, −1.4 (minor rotamer). Anal. calcd for $C_7H_{17}NO_2Si$: C, 47.96; H, 9.78; N, 7.99. Found: C, 47.91; H, 9.94; N, 8.03.

13. Cyanotriethylsilane has been shown to be an effective trapping agent for transient carbanionic species: Cunico, R.F. *Synth. Commun.* **2000**, *30*, 433.
14. Siloxane appears to originate during the reaction, and was also a component of the mixture obtained when using phenyldimethylchlorosilane as trapping agent. In the preparation of **6a**, hexamethyldisiloxane would be lost upon workup and may account for some of the unrealized yield of carbamoylsilane.
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17. Typical procedure: A fused 3-bulb Kugelrohr receiver was mounted vertically, charged with dry CsF (ca. 50 mg), and strongly heated at 1 mmHg. Argon was introduced, followed by 225 mg (1.3 mmol) of **6a** and 220 mg (1.3 mmol) of $PhMe_2SiCl$. The mixture was held at 145°C for 1 h 40 min, cooled and evacuated momentarily to 1 mmHg, and then heated under Ar again for an additional 50 min. Necessary heating times varied with the chlorosilane, and sometimes 0.5–1 molar excess of chlorosilane was used. Periodic monitoring of the reaction by NMR offered the best indication of completeness. The contents were then Kugelrohr distilled (160°C, 0.1 mmHg) to give 203 mg (67%) of **6d**. IR 1584 cm^{-1}; ^{1}H NMR (500 MHz, C_6H_6): δ 7.29 (m, 5H), 4.31 (s, 2H), 2.90 (s, 3H), 2.75 (s, 3H), 0.62 (s, 6H) (major rotamer); 7.61 (m, 5H), 4.82 (s, 2H), 3.21 (s, 3H), 2.63 (s, 3H), 0.58 (s, 6H) (minor rotamer). ^{13}C NMR (126 MHz, C_6H_6): δ 186.7, 136.3, 134.0, 129.7, 128.2, 80.8, 53.9, 30.5, −2.4 (major rotamer); 186.3, 136.0, 133.7, 128.3 (one phenyl carbon coincident or obscured by solvent), 74.7, 55.3, 33.1, −2.7 (minor rotamer). Anal. calcd for $C_{12}H_{19}NO_2Si$: C, 60.72; H, 8.07; N, 5.90. Found: C, 60.55; H, 8.20; N, 5.82.