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An improved preparation of enamines of acylsilanes, a new synthesis of acylsilanes *

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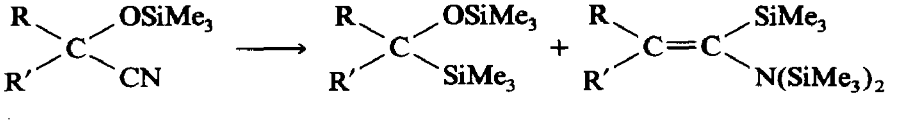
Abstract

The use as solvent of hexamethylphosphortriamide instead of the previously used tetrahydrofuran has allowed the synthesis in high yield of enamines of acylsilanes (**2**) from cyanohydrins (**1**) by reductive silylation with Me_3SiCl/Li. Protodesilylation of **2a** ($R = R' = Me$) by HCl gas in dry diethyl ether or by trimethylchlorosilane in methanol gave, after neutralization, a quantitative yield of the enamine $Me_2C{=}C(SiMe_3)NH_2$, which was surprisingly stable. Its ready hydrolysis to the corresponding acylsilane provided a new route to this type of compound. Reaction of bromine with **2a** gave α-bromoisobutyronitrile.

Introduction

Enamines of acylsilanes have been described previously [1] but the method of synthesis, involving reductive silylation of cyanohydrins with lithium in the presence of trimethylchlorosilane in tetrahydrofuran (THF) as solvent had some drawbacks. In particular, the conversion of the starting material was never complete, predominant or exclusive formation of the corresponding α-siloxysilane was generally observed, and aldehyde cyanohydrins gave complex mixtures of compounds, with only poor yields of enamines (eq. 1):



$$\mathrm{RR'C(OSiMe_3)(CN)} \longrightarrow \mathrm{RR'C(OSiMe_3)(SiMe_3)} + \mathrm{RR'C{=}C(SiMe_3)N(SiMe_3)_2} \qquad (1)$$

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* Some of this work was described at the Eight International Symposium on Organosilicon Chemistry, St Louis, Missouri (USA), 1987.

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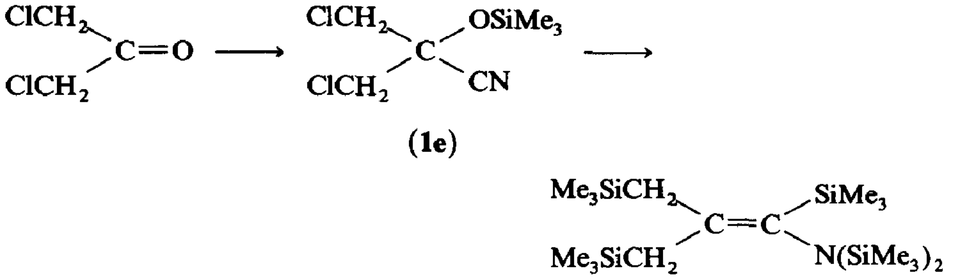
A radical-anion mechanism was proposed for the reaction. We expected that the use of a more polar solvent than THF would facilitate the transfer of electrons from the metal to the substrate and so possibly give much better results. In spite of the fact that treatment of trimethylchlorosilane with lithium in the presence of hexamethylphosphortriamide (HMPA) has been reported [2] to afford disilanes in high yields, we nevertheless decided to examine this reductive silylation of cyanohydrins in HMPA.

Results

Cyanohydrins **1** from various ketones and aldehyde were treated with lithium sand and trimethylchlorosilane in HMPA at 0 °C. Enamines **2** were exclusively formed, and were isolated in excellent yields. The results are summarized in Table 1 along with those from the THF procedure.

Compound **2c** was obtained as 50/50 mixture of the *Z* and *E* isomers, whereas **2d** was obtained as a single isomer with the *E* structure.

The cyanohydrin **1e** from α,α'-dichloromethyl acetone was treated in the same way to give the corresponding enamine **2e**, in which the two chlorine atoms have been replaced by two trimethylsilyl groups, in an enhanced yield (50% in THF, 71% in HMPA; eq. 2).



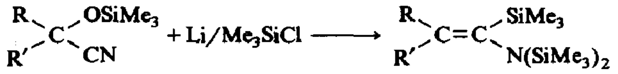
(1e)

(2e)

(2)

Table 1

Preparation of enamines of acylsilanes (2)

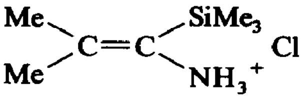


(1) (2)

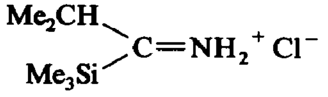
Enamine	R, R'	Solvent	Yield (%)
2a	Me, Me	THF	24
2a	Me, Me	HMPA	82
2b	$(CH_2)_5$	THF	19
2b	$(CH_2)_5$	HMPA	80
2c	n-Pr, Me	THF	25
2c	n-Pr, Me	HMPA	80
2d	t-Bu, H	THF	10
2d	t-Bu, H	HMPA	68

In an attempt to hydrolyze the representative enamine **2a** a methanolic solution of this compound containing a few drops of concentrated hydrochloric acid was refluxed for 1 week, but surprisingly the starting material was quantitatively recovered.

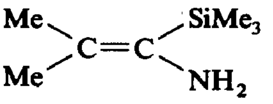
In contrast, treatment of an etheral solution of **2a** with dry hydrogen chloride led to an exothermic reaction and formation of a white powder which was shown to be the hydrochloride of the *N*-desilylated enamine, **3a**. This salt was also obtained by refluxing for one hour a methanolic solution of **2a** in the presence of one equivalent of trimethylchlorosilane and evaporating off the solvent and the methoxytrimethylsilane formed. Yields were quantitative in both cases. Neutralization of **3a** with saturated aqueous sodium bicarbonate yielded the free enamine **4a**. Compounds **3a** and **4a** slowly isomerized to the corresponding imines **5a** and **6a** respectively (15% after 3 h).



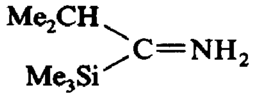
(3a)



(5a)

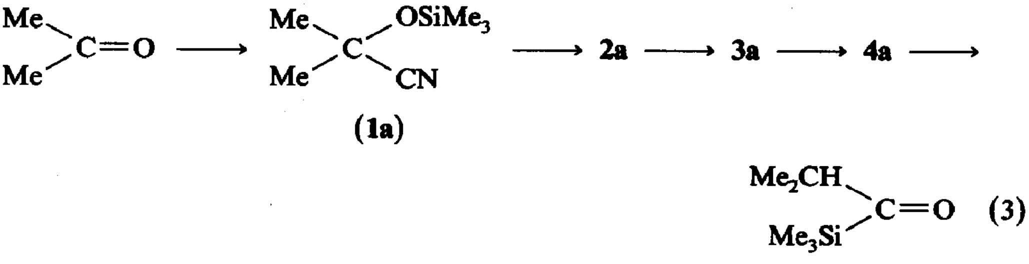


(4a)



(6a)

When an etheral solution of **4a** (or **6a** or a mixture of both) was treated with dilute hydrochloric acid, isobutyroxytrimethylsilane (**7a**) was obtained as a pale yellow liquid in 67% yield (from **2a**) (eq. 3).

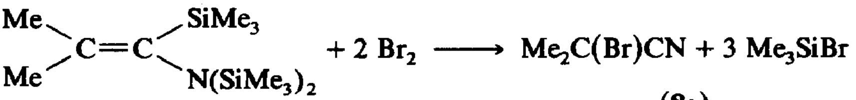


(1a) (3)

(7a)

The reactions **2a**–**7a** can be performed by one pot procedure and the overall transformation represent a new convenient synthesis of acylsilanes [3,4], a class of compounds of synthetic value [5]. As these compounds can be readily desilylated to give the corresponding aldehydes [6], the overall reaction constitutes a new procedure has homologization of ketones and aldehydes which compares favorably with other available methods [7].

Some other reactions of **2a** were also examined; treatment of **2a** with chlorine, iodine, iodine chloride, and cyanogen iodide, either neat or in carbon tetrachloride, with or without an ionic ($AlCl_3$) catalyst or UV irradiation gave only unchanged material in yields of up to 90%. However, bromine in carbon tetrachloride reacted readily to give quantitative yields of 2-bromo-2-methyl-propionitrile and trimethylbromosilane. Addition of only one equivalent of bromine gave a 1/1 mixture of **2a** and **8a** (eq. 4).



$$\mathrm{Me_2C{=}C(SiMe_3)N(SiMe_3)_2 + 2\,Br_2 \longrightarrow Me_2C(Br)CN + 3\,Me_3SiBr} \qquad (4)$$

(2a) **(8a)**

The possibility of cycloaddition reactions with α-chloroacrylonitrile and diethyl acetylene carboxylate (sealed tube, 150 ° C, 4 days) was examined, but none of the expected products were obtained and **2a** was recovered quantitatively.

It seems evident that the steric hindrance around the enamine system and the very low nucleophilicity of the nitrogen atom bearing two trimethylsilyl groups [8], are important factors. Thus protodesilylation of enamines **2** initiated by protonation at the nitrogen atom, such as it is assumed normally to take place with enamines [9], is ruled out in this case. Probably attack by nucleophiles (Cl^- or MeO^-) at one of the silicon atoms linked to nitrogen, to form a pentacoordinated intermediate, is the starting point of the protodesilylation of these compounds.

Experimental

General data. Analytical GLC was performed with an Intersmat gas chromatograph equipped with a catharometer detector and fitted with SE 30 silicone (10%) on Chromosorb P as packing. Infrared spectra were recorded with neat products on a Perkin Elmer 1420 IR spectrophotometer. The NMR spectra were recorded on a Perkin Elmer Hitachi R-24-B spectrometer (60 MHz) for ^1H, a Bruker WH-60 spectrometer (15.07 MHz) for ^{13}C, and a Bruker WH-90 spectrometer (17.87 MHz) for ^{29}Si. Mass spectra were obtained with a Micromass 16-F mass spectrometer (70 eV). All new products gave elemental analyses in good agreement with the proposed structures.

Trimethylchlorosilane generously supplied by Société Rhône-Poulenc (France), was distilled over magnesium turnings prior to use. Lithium sand (0.1–0.5% Na), from Prolabo, was used after removal of the paraffin oil by washing with dry ether. Hexamethylphosphortriamide (HMPA), obtained from Aldrich and kept under argon, was used as received. Cyanohydrins **1** were prepared as previously reported [1], and the physical properties of known compounds were in good agreement with those previously reported [1]. The new compound **1e** obtained in 90% yield had b.p.: 115 ° C/20 torr; ^1H NMR (CCl_4): δ 0.33 s ($SiMe_3$) 3.4 s (CH_2Cl); IR: no μ(CN) band present. (Found: C, 37.01; H, 5.86; Cl, 31.08; N, 6.09. $C_7H_{13}Cl_2NOSi$ calcd.: C, 37.18; H, 5.79; Cl, 31.35; N, 6.19%.)

Synthesis of enamines 2. In a dry flask flushed with argon, equipped with a magnetic stirring bar and closed with a septum, were placed lithium sand (6.4 g, 900 mmol), dry ether (100 ml) and Me_3SiCl (100 ml, 770 mmol). The mixture was cooled to −10 ° C and cyanohydrin **1** (100 mmol) was introduced from syringe and then HMPA (75 ml, 430 mmol) was added dropwise during 20 min. The mixture was kept at 0 ° C for 3 h and then left at room temperature for 3 h. The precipitated salts and remaining lithium sand were filtered off and washed with pentane, and the solvent and excess of Me_3SiCl were evaporated from the combined filtrate and washings. The resulting oil was taken up in pentane and the solution washed successively with cold water, 1 *N* hydrochloric acid, and aqueous sodium bicarbonate. Drying over sodium sulfate and evaporation of the solvent afforded a fairly pure product, whose properties (IR, NMR, elemental analysis) were in good agreement with thoses expected [1] for the relevant compounds **2**. Yields are reported in Table 1. Compounds **2** have been described previously [1] except for enamine **2e**: (Found: C, 52.71; H, 11.57; N, 3.31; Si, 32.17. $C_{19}H_{49}NSi_5$ calcd.: C, 52.83; H, 11.43; N, 3.24; Si, 32.50%.) ^{1}H NMR (CCl_4): δ 0.24s (18H, $SiMe_3$), 0.26s (18H, $SiMe_3$), 0.33s (9H, $SiMe_3$), 1.91s (2H, CH_2), 1.92s (2H, CH_2).

*Protolysis of **2a**:* (i) With methanol/hydrochloric acid. A mixture of **20** (10 g, 35 mmol), methanol (60 ml), and a few drops of concentrated HCl was refluxed for 1 week. After neutralization with sodium bicarbonate and evaporation of the solvent, the starting material was recovered almost quantitatively (9.5 g).

(ii) With dry HCl in diethyl ether. Dry HCl gas was bubbled for 15 min through a magnetically stirred solution of **2a** (8.1, 28 mmol) in diethyl ether (40 ml). An exothermic reaction took place and a white precipitate appeared. Dry nitrogen was bubbled through the reaction mixture to remove residual HCl and the precipitate (4.7 g) was filtered off and identified as the chlorohydrate **3a**: yield 93%; m.p. 160 °C; NMR ($(CD_3)_2SO$, C_6D_6): δ 0.3s ($SiMe_3$), 1.8s (Me), 1.9s (Me) (Found: Cl, 19.98; $C_7H_{18}ClNSi$ calcd.: Cl, 19.72%.)

(iii) With trimethylchlorosilane/methanol. A mixture of the enamine **2a** (10 g, 35 mmol), methanol (60 ml), and trimethylchlorosilane (4 g, 37 mmol) was kept at 60 °C for 3 h. Evaporation of the solvent and the methoxytrimethylsilane formed left 6.1 g of **3a** as a white solid (yield 98%).

*Formation of the imine salt **5a**.* When kept under dry nitrogen **3a** isomerized slowly into the imine salt **5a** (as monitored by ^{1}H NMR, 15% in 3 h): ^{1}H NMR (as above): δ 0.4s ($SiMe_3$), 1.13–1.33d (J 6.5 Hz, Me_2C), 3.2m (J 6.5 Hz, CH); IR: 1665 cm^{-1} (ν(C=N)).

*Obtention of the free enamine **4a**.* A solution of **3a** (7.6 g, 40 mmol) in ether (20 ml) was neutralized with aqueous sodium bicarbonate. The layer, combined with ether washings of the aqueous layer, was dried over sodium sulfate and evaporated to leave an oily residue (5.8 g), which was identified as the free enamine **4a** (96% yield), with ^{1}H NMR data very close to those of its salt but showing a band at 3300–3400 cm^{-1} ($\nu(NH_2)$) in the IR. This compound isomerized slowly to the corresponding imine **6a** (20% in 2 h), which gave a spectrum very close to those of its salt and showed an NH band in its IR spectrum.

*Preparation of isobutyroxytrimethylsilane (**7a**).* A mixture of enamine **4a** (5.2 g), or a mixture of **4a** and **6a**, in ether (20 ml) with dilute aqueous hydrochloric acid was stirred overnight. The mixture must be kept neutral or slightly acidic). The ether layer was separated, washed with water, and dried over sodium sulfate. The ether was evaporated and the residue distilled to give 4.5 g of the silane **7a** (85% yield; 67% from **2a**): ^{1}H NMR (CCl_4): δ 0.2s ($SiMe_3$), 1.03d (J 6.5 Hz, Me_2C), 2.7m (J 6.5 Hz, CH); IR: 1635 cm^{-1} (ν(Si–C=O). These data are in good agreement with those in the literature [10].

Addition of bromine. To a stirred solution of the enamine **2a** (2.87 g, 10 mmol) in carbon tetrachloride (20 ml) bromine (3.2 g, 20 mmol) was slowly added with the mixture cooled in an ice bath because a very exothermic reaction took place. The NMR spectrum of the colourless solution showed, in addition to the α-bromo nitrile

8a, the presence of trimethylbromosilane (3 equiv.) (δ 0.7). After evaporation of the solvent and the bromosilane under vacuum, **8a** was obtained practically pure (1.55 g): yield, 98%; b.p. 136–140 °C/760 torr (lit. [11] 135–140 °C/760 torr); ^1H NMR (CCl_4): δ 2.1s (Me_2C). When only one equivalent of bromine was used under the same conditions, a 50/50 mixture of **2a** and **8a** was obtained.

Attempted reaction of ***2a****.* With other halogens and pseudohalogens. In a procedure similar to that described above, **2a** was treated with chlorine, iodine, iodine chloride and cyanogen iodide. The carbon tetrachloride solution was heated under reflux for several hours but the starting material was recovered unchanged. The same result was obtained when the mixture of the neat compounds were heated, even in the presence of possible catalysts as aluminum chloride or under UV irradiation.

Attempted cycloadditions with ***2a****.* Two argon filled sealed ampoules were prepared containing 3 g of enamine **2a** and either α-chloroacrylonitrile (1 g) or methylacetylene carboxylate (1.5 g). They were kept at 140 °C for 4 days then cooled. Distillation gave respectively 2.6 and 2.7 g of the starting material.

References and notes

1 J.P. Picard, A. Elyusufi, R. Calas, J. Dunoguès and N. Duffaut, Organometallics, 3 (1984) 1660.

2 H. Sakurai and A. Okada, J. Organomet. Chem., 36 (1972) C13.

3 For previous syntheses cf. W.P. Weber, Silicon Reagents for Organic Synthesis, Springer Verlag, Berlin, 1983, p. 259.

4 D. Ager, Silicon Containing Carbonyl Equivalents, in Chem. Soc. Rev., 11 (1982) 514.

5 D. Ager, Chem. Soc. Rev., 11 (1982) 515.

6 (a) A.G. Brook, J. Am. Chem. Soc., 79 (1957) 4373; (b) A.G. Brook, T.J.D. Vandersac and W. Limburg, Can. J. Chem., 56 (1958) 1758; (c) D. Pietropaolo, M. Fiorenza, A. Ricci and M. Taddei, J. Organomet. Chem., 197 (1980) 7; (d) J. Dunoguès, M. Bolourtchian, R. Calas, N. Duffaut and J.P. Picard, ibid., 43 (1972) 157; (e) C.H. Heathcock and D. Schinzer, Tetrahedron Lett., 22 (1981) 1881.

7 (a) see for instances: Ph. Magnus et al., Tetrahedron, 39 (1983) 867; (b) K. Schonauer and E. Zbiral, Tetrahedron Lett., 24 (1983) 573.

8 R. Fessenden, J.S. Fessenden, Chem. Rev., 61 (1961) 361.

9 (a) E.J. Stamhuis, Hydrolysis of Enamines in A.G. Cook, M. Dekker (Ed.), Enamines, New York, 1969, p. 101; (b) U. Wannagat, The Silicon–Nitrogen Bond in G. Bendz and I. Lundqvist (Eds.), Biochemistry of Silicon and related Problems, Plenum Press, New York, 1978, p. 77.

10 J.P. Picard, A. Ekouya, J. Dunoguès, N. Duffaut and R. Calas, J. Organomet. Chem., 93 (1975) 51.

11 C.L. Stevens, J. Am. Chem. Soc., 70 (1948) 167.