

Synthesis of α -(perfluoroalkyl)- ω -(trialkylsilyl)alkanols

G. N. Molchanova,* P. V. Petrovskii, T. M. Shcherbina, A. P. Laretina, L. S. Zakharov, and M. I. Kabachnik

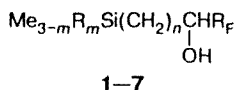
A. N. Nesmeyanov Institute of Organoelement Compounds, Russian Academy of Sciences,
28 ul. Vavilova, 117334 Moscow, Russian Federation.
Fax: +7 (095) 135 5085

The synthesis of alkanols of the general formula $R_3Si(CH_2)_nCH(OH)R_F$ ($n = 1-3$) is elaborated and their behavior under GC-MS is studied.

Key words: α -perfluoroalkyl- ω -trialkylsilylalkanols, synthesis; GC-MS.

Silicon-containing polyfluorinated alcohols^{1,2} are a new, practically unexplored class of compounds. We began the study of phosphorylation of some of them.

This work deals with the synthesis of a series of silapolyfluoroalkanols (1-7).

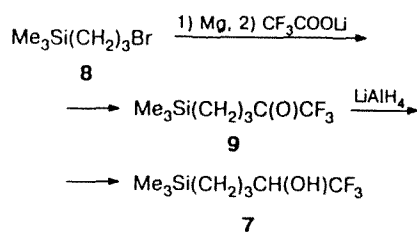


- 1: $m = 0, n = 1, R_F = \text{CF}_3$
 2: $m = 0, n = 1, R_F = \text{C}_4\text{F}_9$
 3: $m = 1, R = \text{CF}_3\text{CH}_2\text{CH}_2, n = 1, R_F = \text{C}_4\text{F}_9$
 4: $m = 3, R = \text{Pr}, n = 1, R_F = \text{C}_4\text{F}_9$
 5: $m = 3, R = \text{CF}_3\text{CH}_2\text{CH}_2, n = 1, R_F = \text{C}_4\text{F}_9$
 6: $m = 0, n = 2, R_F = \text{C}_3\text{F}_7$
 7: $m = 0, n = 3, R_F = \text{CF}_3$

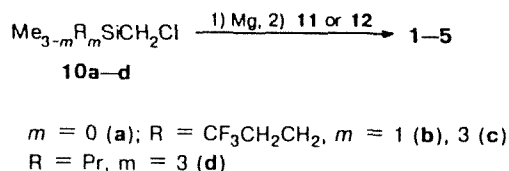
Despite the similarity of the structures, alcohols 1-7 cannot be obtained by a unified route. Thus, the synthesis of 1,1,1-trifluoroalkan-2-ols by the condensation of alkylmagnesium halide with lithium trifluoroacetate³ followed by reduction of the resulting ketone is inappropriate for the preparation of alcohol 1, evidently due to the instability of the product of the first stage, viz., silicon-substituted trifluoroacetone. Alcohols containing two methylene fragments also cannot be synthesized by this method due to the instability of initial (2-chloroethyl)trimethylsilane under the reaction conditions. Only 1,1,1-trifluoro-5-trimethylsilylpentan-2-ol 7 was obtained by the reaction of the Grignard reagent prepared from (3-bromopropyl)trimethylsilane (8) with lithium trifluoroacetate followed by the reduction of ketone 9 with lithium aluminum hydride (Scheme 1).

1-(Polyfluoroalkyl)-2-(triorganylsilyl)ethanols 1-5 could be synthesized by the method used for the preparation of nonfluorinated, silylated secondary alcohols. This method involves the interaction of silicon-containing Grignard reagents with aldehydes.⁴ Alcohols 1-5 were prepared from the corresponding (triorganylsilyl)me-

Scheme 1



Scheme 2

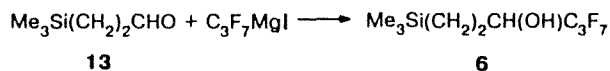


thyl chlorides (10a-d) and trifluoroacetaldehyde (11) or perfluoropentanal (12) (Scheme 2).

At the same time, an attempt to use this method to synthesize fluorinated alcohols, in which the silicon atom is separated from the functional group by three methylene fragments, resulted in a mixture of products, which was difficult to separate.

The synthesis of alcohols with two methylene fragments was performed by the reaction of the corresponding silicon-containing aldehydes with perfluoroalkylmagnesium iodides. For example, 1-perfluoropropyl-3-trimethylsilylpropan-1-ol 6 was obtained from 3-trimethylsilylpropanal (13) and perfluoropropylmagnesium iodide in 45 % yield (Scheme 3).

Scheme 3



Alcohols 1–7 are colorless liquids stable in the course of distillation (at a bath temperature of up to 200 °C), their structures are confirmed by the elemental analysis data (Table 1) and the ^1H and ^{19}F NMR spectra.

The control of purity of alcohols 2–7 shows that the GC-MS method is applicable only for alkanols 2, 3, 6, and 7. These compounds are stable under chromatographic conditions on a capillary column and their chromatograms contain only peaks of the compounds studied. The peaks of $[\text{M}-\text{Me}]^+$ ions, which are the most characteristic of silicon-containing compounds, in the mass spectra of alcohols 2, 3, 6, and 7, were weak or absent altogether. In the same time, one of the most intense ions for all of the above alcohols is the ion at m/z 75 $[\text{Me}_2\text{SiOH}]^+$. The formation of this rearrangement ion may be explained by the migration of the hydroxyl group from the carbon atom to the silicon atom with the elimination of alkene or cycloalkene. The existence of the latter is indicated by the presence of a peak of ion at m/z 227 $[\text{CH}_2=\text{CHC}_4\text{F}_9-\text{F}]^+$ in the mass spectra of alcohols 2 and 3, and the peaks of ions at m/z 191 $[\text{C}_3\text{H}_5\text{C}_3\text{F}_7-\text{F}]^+$ and m/z 105 $[\text{C}_4\text{H}_7\text{CF}_3-\text{F}]^+$ in the spectra of alcohols 6 and 7, respectively.

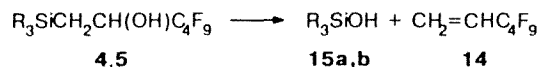
Alcohols 4 and 5 decompose in the course of chromatography, which is confirmed by the presence of two peaks in the chromatogram. In both cases, only the minor peaks (10–20 % in the mixture) correspond to the analyzed alcohols (according mass spectra). It should be noted that the decomposition of alcohols 4 and 5 on the chromatographic column occurs under relatively mild conditions (the retention time is 14–22 min, and the retention temperature is 116–176 °C depending on the parameters of chromatography), while the change in the chromatographic conditions (column temperature program, injector temperature, and carrier gas rate) practically do not decrease the extent of decomposition.

In the mass spectra of alcohols 4 and 5, as in those of alcohols 2 and 3, the ion at m/z 227 $[\text{CH}_2=\text{CHC}_4\text{F}_9-\text{F}]^+$ was observed, which indicates the elimination of alkene. The rearrangement ions at m/z 133 $[\text{Pr}_2\text{SiF}]^+$, m/z 131 $[\text{C}_6\text{H}_{15}\text{SiO}]^+$, and m/z 105 $[\text{C}_3\text{H}_6\text{FSiO}]^+$ are characteristic of alcohol 4, and the ions at m/z 163 $[\text{CF}_3\text{CH}_2\text{CH}_2\text{SiF}_2]^+$ and m/z 141 $[\text{CF}_3\text{CH}_2\text{CH}_2\text{SiO}]^+$ are characteristic of alcohol 5; their formation may be explained by the migration of the fluorine and oxygen atoms to the silicon atom.

The mass spectra of the products of decomposition of alcohols 4 and 5 contain the characteristic ions, which make it possible to assign them to the silanol Pr_3SiOH (15a) (m/z 157 $[\text{Pr}_3\text{Si}]^+$, m/z 131 $[\text{C}_6\text{H}_{15}\text{SiO}]^+$ and m/z 89 $[\text{C}_3\text{H}_9\text{SiO}]^+$) and to silanol $(\text{CF}_3\text{CH}_2\text{CH}_2)_3\text{SiOH}$ (15b) (m/z 163 $[\text{CF}_3\text{CH}_2\text{CH}_2\text{SiF}_2]^+$, m/z 141 $[\text{CF}_3\text{CH}_2\text{CH}_2\text{SiO}]^+$, and

m/z 59 $[\text{C}_2\text{H}_4\text{Si}]^+$), respectively. One can assume that in the course of chromatography on a capillary column, alcohols 4 and 5 undergo thermal decomposition, which gives silanol 15a,b and possibly proceeds with the elimination of polyfluoroalkene 14* (Scheme 4).

Scheme 4



Experimental

The NMR spectra were recorded with a Bruker WP-200SY instrument in CDCl_3 (CHCl_3 and CF_3COOH were taken as the external standards for the ^1H and ^{19}F NMR spectra, respectively). The GC-MS were carried out with a Varian-3400 chromatograph with a DB-1 capillary column (30 m \times 0.32 mm; 0.25 mm film thickness) and temperature programming from 60 to 250 °C. The rate of the temperature program was 6 deg min^{-1} . A Finnigan MAT 800 AT ion trap was used as the detector, and the energy of electron impact was 70 eV.

Bromopropylsilane 8 (see Ref. 5), chloromethylsilanes 10a,c,d (see Ref. 6) were prepared according to the procedures described; the synthesis of silane 10b will be published elsewhere.

1,1,1-Trifluoro-3-(trimethylsilyl)propan-2-ol (1). CF_3CHO 11, prepared by heating perfluoroacetaldehyde hydrate (23 g) with conc. H_2SO_4 , was passed through a solution of the Grignard reagent prepared from a mixture of chlorotrimethylsilane 10a (18.5 g, 0.15 mol) and Mg (3.6 g, 0.15 g-at.) in anhydrous ether (70 mL) cooled to -20 °C. The mixture was warmed to ambient temperature for 1 h and left overnight. The mixture was decomposed with an aqueous solution of H_2SO_4 (3 : 1), the organic layer was separated, and the aqueous layer was extracted with ether. The organic layer was combined with the ethereal extract, washed with water, and dried over MgSO_4 . The solvent was removed, and the residue was distilled *in vacuo* giving alcohol 1 (21.3 g). ^1H NMR, δ : 0.08 (s, 3 H, MeSi); 0.92–0.96 (m, 2 H, CH_2); 2.35 (s, 1 H, OH); 3.97–4.11 (m, 1 H, CH). ^{19}F NMR, δ : -2.29 (s, $J_{\text{H,F}} = 6.8$ Hz).

3,3,4,4,5,5,6,6-Nonafluoro-1-(trimethylsilyl)hexan-2-ol (2). A solution of perfluoropentanal 12 (44.6 g, 0.18 mol) in anhydrous ether (100 mL) was added dropwise to a solution of the Grignard reagent prepared from 10a (24.7 g, 0.20 mol) and Mg (5.3 g, 0.22 g-at.) in anhydrous ether (100 mL), at -40 °C. The mixture was kept for 15 min with cooling, warmed gradually to ambient temperature, then refluxed on a water bath for 2 h and left overnight. After a workup analogous to that for 1, alcohol 2 (48.5 g) was obtained. ^1H NMR, δ : 0.12 (s, 3 H, MeSi); 0.89–1.19 (m, 2 H, CH_2); 1.90 (s, 1 H, OH); 4.28–4.41 (m, 1 H, CH). MS, m/z ($I_{\text{rel}}(\%)$): 227 $[\text{CH}_2\text{CHC}_4\text{F}_8]^+$ (9.7), 75 $[\text{Me}_2\text{SiOH}]^+$ (68.1), 73 $[\text{Me}_3\text{Si}]^+$ (100).

* MS of authentic $\text{CH}_2=\text{CHC}_4\text{F}_9$ (14) has the most abundant ion at m/z 227 $[\text{M}-\text{F}]^+$.

* Under these conditions of chromatography (see Experimental), alkene 14 was not observed.

Table 1. Yields, characteristics, and elemental analysis data for alcohols 1–7 and ketone 9

Compound	Yield (%)	B.p./°C (p/Torr)	n_D^{20}	d_4^{20}	Found (%)			Molecular formula
					Calculated	C	H	Si
1	77	66–68(57)	1.3879	1.0579	38.62 38.71	7.06 6.99	14.79 15.05	C ₆ H ₁₃ F ₃ OSi
2	78	71–72(18)	1.3576	1.3170	32.11 32.14	3.87 3.87	7.92 8.33	C ₉ H ₁₃ F ₉ OSi
3	61	114–116(23)	1.3571	1.3967	31.59 31.59	3.37 3.37	6.53 6.71	C ₁₁ H ₁₄ F ₁₂ OSi
4	57	104(1)	1.3908	1.2059	43.08 42.85	5.99 5.99	6.42 6.68	C ₁₅ H ₂₅ F ₉ OSi
5	49	112(1)	1.3550	1.5507	30.30 30.34	2.73 2.77	4.54 4.42	C ₁₅ H ₁₆ F ₁₈ OSi
6	45	80–81(17)	1.3780	—	36.00 36.00	5.06 5.03	9.60 9.35	C ₉ H ₁₅ F ₇ OSi
7	87	76(10)	1.3980	1.0245	44.80 44.84	8.28 7.99	13.17 13.11	C ₈ H ₁₇ F ₃ OSi
9	51	73(45)	1.3800	1.0052	44.87 45.26	7.09 7.12	13.07 13.23	C ₈ H ₁₅ F ₃ OSi

1-[Dimethyl-(3,3,3-trifluoropropyl)silyl]-3,3,4,4,5,5,6,6,6-nonafluorohexan-2-ol (3). Alcohol 3 (10.8 g) was prepared from (chloromethyl)(3,3,3-trifluoropropyl)dimethylsilane **10b** (8.7 g, 0.04 mol), Mg (1.0 g, 0.04 g-at.), and **12** (10.5 g, 0.04 mol) analogously to **2**. ¹H NMR, δ : 0.13 and 0.14 (both s, 6 H, Me₂Si); 0.79–0.88 (m, 2 H, SiCH₂CH₂); 1.00–1.13 (m, 2 H, CH₂CH); 1.93–2.16 (m, 3 H, CF₃CH₂, OH); 4.11–4.36 (m, 1 H, CH). MS, m/z (I_{rel} (%)): 227 [CH₂CHC₄F₈]⁺ (6.3), 75 [Me₂SiOH]⁺ (66.0), 59 [Me₂SiH]⁺ (100).

3,3,4,4,5,5,6,6,6-Nonafluoro-1-(tripropylsilyl)hexan-2-ol (4). Alcohol 4 (23.9 g) was prepared from (chloromethyl)tripropylsilane **10d** (20.1 g, 0.1 mol), Mg (2.4 g), and **12** (24.8 g, 0.1 mol) analogously to **2**. ¹H NMR, δ : 0.55–0.68 (m, 2 H, CH₂CH₂Si); 0.97 (t, 3 H, CH₃, $J_{H,H} = 7.1$ Hz); 1.26–1.46 (m, CH₂CH₂Si); 1.85 (s, 1 H, OH); 4.12–4.31 (m, 1 H, CH). MS, m/z (I_{rel} (%)): 227 [CH₂CHC₄F₈]⁺ (23.0), 157 [Pr₃Si]⁺ (70.3), 133 [Pr₂SiF]⁺ (56.9), 131 [C₆H₁₅SiO]⁺ (11.3), 105 [C₃H₆FSiO]⁺ (100).

3,3,4,4,5,5,6,6,6-Nonafluoro-1-[tris(3,3,3-trifluoropropyl)silyl]hexan-2-ol (5). Alcohol 5 (17.2 g) was prepared from (chloromethyl)tris(3,3,3-trifluoropropyl)silane **10c**⁶ (22.1 g, 0.06 mol), Mg (1.4 g, 0.06 g-at.), and **12** (14.9 g, 0.06 mol), analogously to **2**. ¹H NMR, δ : 0.89–1.39 (m, 8 H, CH₂CH₂Si, SiCH₂CH); 1.97–2.19 (m, 6 H, CF₃CH₂); 2.32 (s, 1 H, OH); 4.20–4.39 (m, 1 H, CH). MS, m/z (I_{rel} (%)): 227 [CH₂CHC₄F₈]⁺ (2.8), 163 [CF₃CH₂CH₂SiF₂]⁺ (17.7), 141 [CF₃CH₂CH₂SiO]⁺ (1.9), 97 [CF₃CH₂CH₂Si]⁺ (11.0), 77 [C₃H₃F₂]⁺, 59 [C₂H₇Si]⁺ (100).

3-(Trimethyl)silylpropanal (13). 3-(Trimethylsilyl)propan-1-ol (13.2 g, 0.1 mol) in dry CH₂Cl₂ (10 mL) was added to a suspension of pyridinium chlorochromate (30 g) in dry CH₂Cl₂ (40 mL) on cooling with cold water. The mixture was stirred for 3 h, the solution was decanted from the precipitate, and the precipitate was washed with ether. The solvent was removed, and the residue was distilled *in vacuo* giving aldehyde

13 (2.7 g, 20.8 %), b.p. 51 °C (30 Torr), n_D^{20} 1.4220 (cf. Ref. 7).

4,4,5,5,6,6,6-Heptafluoro-1-trimethylsilylhexan-3-ol (6). C₃F₇I (7.1 g, 0.024 mol) in ether (10 mL) was added to a solution of EtMgBr, prepared from EtBr (2.18 g, 0.02 mol) and Mg (0.48 g, 0.02 g-at.) in anhydrous ether (20 mL), at –50 °C. The mixture was stirred for 0.5 h, and 3-trimethylsilylpropanal **13** (2.60 g, 0.02 mol) in anhydrous ether (7 mL) was added at the same temperature. The mixture was stirred for 1 h and left overnight. The mixture was worked up as described for **1**, and alcohol **6** (2.67 g) was obtained. ¹H NMR, δ : 0.05 (s, 3 H, Me); 0.35–0.97 (m, 2 H, SiCH₂); 1.50–1.90 (m, 2 H, CCH₂C); 2.70 (s, 1 H, OH); 3.91–4.09 (m, 1 H, CH). MS, m/z (I_{rel} (%)): 285 [M–Me]⁺ (7), 191 [(CH₂)₂CHC₃F₆]⁺ (5), 75 [Me₂SiOH]⁺ (39), 73 [Me₃Si]⁺ (100).

1,1,1-Trifluoro-5-(trimethylsilyl)pentan-2-one (9). CF₃COOLi (46.8 g, 0.39 mol) in anhydrous THF (150 mL) was added dropwise to a stirred solution of the Grignard reagent, prepared from (3-bromopropyl)trimethylsilane **8** (45.3 g, 0.23 mol) and Mg (5.6 g, 0.23 g-at.) in anhydrous ether (300 mL), at –60 °C; the mixture was stirred for 30 min, then refluxed for 1 h and left overnight. The mixture was worked up as described for **1**. Ketone **9** (25.2 g) was obtained by vacuum distillation. ¹H NMR, δ : 0.01 (s, 3 H, Me); 0.26–0.56 (m, 2 H, SiCH₂); 1.59–1.75 (m, 2 H, CCH₂C); 2.71 (t, 2 H, CH₂C=O, $J_{H,H} = 7.1$ Hz).

1,1,1-Trifluoro-5-(trimethylsilyl)pentan-2-ol (7). Ketone **9** (4.80 g, 0.023 mol) in anhydrous ether (50 mL) was added to a stirred suspension of LiAlH₄ (0.86 g, 0.023 mol) in anhydrous ether (30 mL). The mixture was refluxed for 1 h and quenched with water (10 mL), and then with an aqueous solution of H₂SO₄ (3 : 1). The mixture was worked up as described for **1** giving alcohol **7** (4.2 g). ¹H NMR, δ : 0.00 (s, 3 H, Me); 0.44–0.58 (m, 2 H, SiCH₂); 1.33–1.75 (m, 4 H, CCH₂CH₂C); 2.38 (s, 1 H, OH); 3.87–3.99 (m, 1 H, CH).

^{19}F NMR, δ : -2.32 (s, $J_{\text{H,F}} = 6.9$ Hz). MS, m/z ($I_{\text{rel}}(\%)$): 199 $[\text{M}-\text{Me}]^+$ (13.1), 105 $[(\text{CH}_2)_3\text{CHCF}_2]^+$ (3.6), 75 $[\text{Me}_2\text{SiOH}]^+$ (49.7), 73 $[\text{Me}_3\text{Si}]^+$ (100), 59 $[\text{Me}_2\text{Si}!\text{I}]^+$ (100).

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