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Regioselective chelation in the reaction of *N*-trimethylsilyl-*N*-acetylglycine *N'*,*N'*-dimethylamide with chloro(chloromethyl)dimethylsilane

Sergey Yu. Bylikin,[a,b] **Alexander A. Korlyukov,***[a,c] **Alexander G. Shipov,**[a] **Dmitry E. Arkhipov,**[a,c] **Natalia A. Kalashnikova,**[a] **Vadim V. Negrebetsky**[a] **and Yuri I. Baukov***[a]

[a] *N. I. Pirogov Russian National Research Medical University, 117997 Moscow, Russian Federation. Fax: +7 495 434 0329; e-mail: baukov@rsmu.ru*
[b] *The Open University, Walton Hall, Milton Keynes, MK7 6AA UK. Fax: +44 01908 632 182; e-mail: bylikin@chemlet.com*
[c] *A. N. Nesmeyanov Institute of Organoelement Compounds, Russian Academy of Sciences, 119991 Moscow, Russian Federation. Fax: +7 499 135 5085; e-mail: alex@xrlab.ineos.ac.ru*

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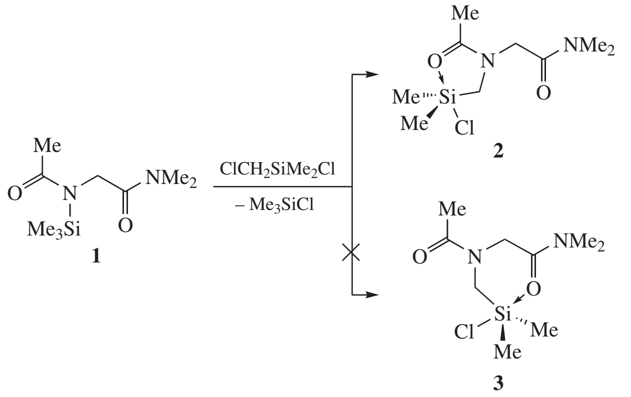
Regioselective reaction of *N*-trimethylsilyl-*N*-acetylglycine *N'*,*N'*-dimethylamide with chloro(chloromethyl)dimethylsilane yields chlorosilane $MeC(O)N(CH_2SiMe_2Cl)CH_2C(O)NMe_2$ with a five-membered C,O-chelate ring involving the *N*-acetyl group rather than the six-membered ring involving the *N'*,*N'*-dimethylamide fragment. According to X-ray data, the pentacoordinate silicon atom in the product has a TBP environment with the halogen and oxygen atoms in axial positions.

Neutral monochlorosilanes containing a pentacoordinate silicon atom and monoanionic amidomethyl or similar C,O-chelating ligands are well known.[1] The strength of the intramolecular O→Si coordination in these silanes and their derivatives with a SiC_3OX (X = Hal, OAlk, OAr, $^1/_2$O, OTf) fragment[1,2] varies in a wide range, which allows one to study their structural features,[1,2] stereochemical behaviour[3] and the nature of hypervalent interaction[1(*b*),4] in their molecules. In addition, such compounds can be used as models of the S_N2 reaction pathway at the silicon atom.[1,2(*a*),5] At the same time, complexes of pentacoordinate silicon with amino acids as C,O-chelate amidomethyl ligands are virtually unknown. The only described analogues of the latter compounds are diketopiperazine derivatives.[6(*a*),(*b*)]

In our recent publications, chemical transformations of 1-organosulfonyl-2-sila-5-piperazinones into 2-aminoacid derivatives[6(*c*)] and the first examples of pentacoordinate (O→Si)-chelate chlorosilanes RSO_2-Pro-N(Me)CH_2SiMe_2Cl with a proline fragment[6(*d*)] are described. In this paper, we report the reaction of *N*-acetylglycine derivative **1** with $ClCH_2SiMe_2Cl$ and the X-ray diffraction study of the resulting chlorosilane, MeC(O)-N(CH_2SiMe_2Cl)$CH_2C(O)NMe_2$ **2**, with a fragment of glycine.

The reaction of *N'*,*N'*-disubstituted amides of *N*-TMS-*N*-acyl-2-aminoacids can potentially lead to pentacoordinate dimethylchlorosilanes of two types, containing either a five-membered chelate ring involving the oxygen of the acyl group or a six-membered chelate ring involving the oxygen of the amino acid fragment. In the case of dimethylamide **1**, the reaction product contains a five-membered C,O-chelate ring coordination (compound **2**) rather than a six-membered ring (compound **3**).[†]



The reaction was carried out under thermodynamically controlled conditions that allowed isolating only the final product of N-silylmethylation (see detailed scheme in ref. 7).

^{1}H, ^{13}C NMR spectra of complex **2** at room temperature display only one set of signals. The hydrogen and carbon atoms of the NMe_2 group were shown to be anisochronic under the same conditions. The observed anisochronicity of signals is suggested to be due to the restricted rotation around the amide bond. Upfield shift in the ^{29}Si NMR spectra[†] provides evidence for pentacoordination of the silicon atom in the complex.

[†] ^{1}H, ^{13}C and ^{29}Si NMR spectra (300, 75 and 79.4 MHz, respectively) of compounds in $CDCl_3$ were recorded on Bruker Avance II 300 and Bruker Avance 400 instruments. The starting materials and solvents were obtained from Sigma–Aldrich.

N-*Acetyl*-N-*trimethylsilylglycine* N',N'-*dimethylamide* **1**. A mixture of 8.07 g (56 mmol) of *N*-acetylglycine *N'*,*N'*-dimethylamide (obtained in 94% yield from *N*-acetylglycine ethyl ester and excess 40% aqueous dimethylamine[10]), trimethylchlorosilane (12.1 g, 112 mmol) and NEt_3 (70 ml) was refluxed for 4 h and allowed to cool down to ambient temperature. The solids formed were filtered off, the solvent was removed *in vacuo* and the remaining oil was distilled. Yield 8.20 g (68%), bp 113–114 °C/0.2 mbar. Found (%): C, 49.65; H, 9.08; N, 12.73. Calc. for $C_9H_{20}N_2O_2Si$ (%): C, 49.96; H, 9.32; N, 12.95.

N-*Acetyl*-N-*(dimethylchlorosilylmethyl)glycine* N',N'-*dimethylamide (O→Si)-chelate* **2**. A solution of chloro(chloromethyl)dimethylsilane (2.86 g, 20 mmol) in Et_2O (15 ml) was added dropwise to a solution of **1** (4.33 g, 20 mmol) in the same solvent (30 ml). The resulting solution was stirred at ambient temperature for 24 h. The crystals formed were filtered, washed with diethyl ether (2×30 ml) and dried *in vacuo*. Yield 3.50 g (70%), mp 135–137 °C (benzene). ^{1}H NMR ($CDCl_3$) δ: 0.58 (s, 6H, $SiMe_2$), 2.04 (s, 3H, MeCO), 2.75 (s, 2H, $SiCH_2$), 2.98 and 3.00 (2s, 6H, NMe_2), 4.16 (s, 2H, NCH_2C). ^{13}C NMR ($CDCl_3$) δ: 6.78 ($SiMe_2$), 17.39 (*Me*CO), 35.94 and 36.28 (NMe_2), 43.34 ($SiCH_2$), 50.85 (N*C*H$_2$C), 164.75 (Me_2N*C*O), 175.49 (Me*C*O). ^{29}Si NMR ($CDCl_3$) δ: –34.32. Found (%): C, 42.94; H, 7.51; N, 10.98. Calc. for $C_9H_{19}ClN_2O_2Si$ (%): C, 43.10; H, 7.64; N, 11.17.

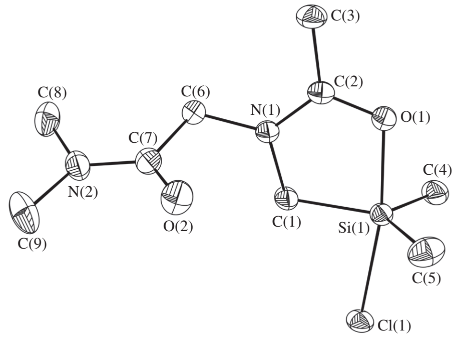


Figure 1 Crystal structure of compound **2**. The hydrogen atoms are omitted for clarity. Selected bond lengths (Å) and angles (°): Si(1)–Cl(1) 2.3564(6), Si(1)–O(1) 1.9414(12), Si(1)–C(1) 1.8782(17), Si(1)–C(4) 1.8596(18), Si(1)–C(5) 1.8586(19), O(1)–C(2) 1.2802(19), O(2)–C(7) 1.222(2), N(1)–C(2) 1.314(2), N(1)–C(6) 1.451(2), N(1)–C(1) 1.467(2), N(2)–C(7) 1.349(2), N(2)–C(9) 1.454(2), N(2)–C(8) 1.460(2), C(2)–C(3) 1.490(2), C(6)–C(7) 1.528(2); C(5)–Si(1)–C(4) 118.44(9), C(5)–Si(1)–C(1) 121.02(9), C(4)–Si(1)–C(1) 120.46(9), C(5)–Si(1)–O(1) 90.51(7), C(4)–Si(1)–O(1) 93.10(7), C(1)–Si(1)–O(1) 83.70(6), C(5)–Si(1)–Cl(1) 93.04(6), C(4)–Si(1)–Cl(1) 92.49(6), C(1)–Si(1)–Cl(1) 87.37(5), O(1)–Si(1)–Cl(1) 170.99(4).

The presence of a five-membered chelate ring in complex **2** in crystal state was determined by the X-ray diffraction study[‡] (Figure 1).

The silicon atom in the crystal of **2** has a distorted TBP environment, with Si(1) displaced from the plane of equatorial substituents towards Cl(1) by 0.0306(4) Å. The O(1)Si(1)Cl(1) angle [170.99(4)°] is significantly smaller than 180°. The distortion of the O(1)Si(1)Cl(1) fragment from linearity is caused by the weakening of the Si(1)–Cl(1) bond [2.3564(6) Å], which is 0.25–0.30 Å longer than similar covalent bonds in organochlorosilanes.[8] The Si(1)–O(1) distance is 1.9414(12) Å, which is also by *ca.* 0.3 Å longer than typical Si–O covalent bonds.[8] The interatomic distance Si(1)···O(2) is 4.3505(14) Å, which excludes the possibility of an additional O→Si interaction in the crystal.

To analyze why five-membered chelate **2** is more favourable than six-membered chelate **3** the quantum chemical calculations of their isolated molecules were carried out[§] (see detailed description in Online Supplementary Materials). The optimization of complex **3** leads to the cleavage of the coordination bond Si(1)–O(2), so the silicon atom became tetracoordinated [the interatomic distances Si(1)···O(1) and Si(1)···O(2) are 3.586 and 3.329 Å, respectively]. In addition, complex **2** is proved to be more thermodynamically stable than complex **3** (ΔE = = 4.9 kcal mol^{-1}). The presence of the Si(1)–O(2) coordination bond in complex **3** leads to a significant ring strain that outweighs the gain in the total energy owing to chelate bond formation.

In the complexes with five-membered chelate rings, the Si(1)–O(1) bond becomes shorter upon the transition from isolated molecule to a polar medium.[9] Thus, we carried out the SCRF calculations of complexes **2** and **3** (PCM model, solvent chloroform) to evaluate the chemical shifts of the silicon atoms ($\delta_{^{29}\mathrm{Si}}$). The geometry of complex **2** in chloroform is closer to that in the crystal [Si(1)–Cl(1) 2.294 Å, Si(1)–O(1) 2.052 Å, Si(1)···O(2) 4.520 Å], while in compound **3** the Si atom remains tetracoordinated [Si(1)–Cl(1) 2.131 Å, Si(1)···O(1) 3.568 Å, Si(1)···O(2) 3.169 Å]. The polar medium stabilizes more polar complex **2** rather than **3** (the dipole moments are 13.4 and 11.72 D, respectively). At the same time, the energy difference between **2** and **3** in chloroform is increased to 6.8 kcal mol^{-1}. The calculated value of $\delta_{^{29}\mathrm{Si}}$ in complex **2** (–36.0 ppm) is in good agreement with experimental value (–34.32 ppm). On the other hand, the $\delta_{^{29}\mathrm{Si}}$ value for **3** (+33.0 ppm) is typical of tetracoordinated silicon.

Thus, the results of our studies demonstrate the preferential formation of five-membered C,O-chelate rings in the complexes of pentacoordinate silicon with intramolecular O→Si coordination, the products of chlorosilylmethylation of N′,N′-disubstituted amides of *N*-acyl-*N*-TMS-2-amino acids.

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Online Supplementary Materials

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.mencom.2015.03.011.

[‡] *Crystal data*. Monoclinic crystals of **2** ($C_9H_{19}ClN_2O_2Si$) were obtained from its solution in a mixture of benzene and hexane, space group $P2_1/c$, a = 10.5830(8), b = 13.1839(10) and c = 9.8088(7) Å, β = 106.928(1)°, V = 1309.28(17) Å^3, Z = 4, M = 250.80, d_{calc} = 1.272 g cm^{-3}, μ(MoKα) = = 3.69 cm^{-1}, F(000) = 536. The intensities of 14914 reflections were measured on a Bruker Smart 1000 diffractometer at 120 K [λ(MoKα) = = 0.71073 Å, ω-scanning, $2\theta_{\max}$ = 59.98°]; 3790 independent reflections (R_{int} = 0.0267) were used for solving and refining the structure. The structure was solved by direct method and refined by full-matrix technique against F^2 in the anisotropic approximation. The positions of hydrogen atoms in methyl and methylene groups were calculated geometrically and refined in rigid body approximation. Final R factors: R_1 = 0.0410 [2852 reflections with $I > 2\sigma(I)$], wR_2 = 0.0882 (all reflections), GOF = 1.002.

CCDC 993829 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre *via* http://www.ccdc.cam.ac.uk.

[§] *Quantum Chemical Calculations*. Computational studies were carried out using the Gaussian09 program.[11] The structures described in respective section were optimized using PBE0/6-311G(d,p) method/basis set with subsequent calculation of Hessian matrix. SCRF calculations were carried out with PCM. $\delta_{^{29}\mathrm{Si}}$ values were calculated using PBE0/IGLO-III method/basis in SCRF mode for optimized molecular geometries.

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