JOURNAL OF PHYSICAL ORGANIC CHEMISTRY
J. Phys. Org. Chem. **12**, 668–674 (1999)

Silylation of substituted benzhydroxamic acids: NMR spectra (^{13}C, ^{15}N and ^{29}Si) and structure of *tert*-butyldimethylsilyl derivatives

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Received 13 January 1999; revised 15 April 1999; accepted 23 April 1999

ABSTRACT: Twelve *para*- and *meta*-substituted benzhydroxamic acids were subjected to exhaustive silylation with *N*-(*tert*-butyldimethylsilyl)-*N*-methyltrifluoroacetamide (with 1% of *tert*-butyldimethylsilyl chloride as a catalyst). In all cases only one product was isolated. According to the assigned NMR spectra (^{13}C, ^{15}N, and ^{29}Si), the product is the *Z*-O^1, O^4-bis(*tert*-butyldimethylsilyl) derivative of substituted benzhydroximic acid, independently of the nature of the *para* or *meta* substituent. For structure determination, the ^{29}Si shifts and $^1J(^{13}C, ^{13}CN)$ coupling constants are decisive. The chemical shifts (^{13}C, ^{15}N, ^{29}Si) show dependences on the substituent constants of various kinds: even the ^{13}C shift of the sixth atom from the benzene ring varies with substitution. The ^{13}C and ^{15}N chemical shifts of the C=N moiety exhibit opposite dependences on the substituent; the ^{29}Si shifts of the two silicon atoms are almost equally sensitive to the substituent effects despite their different distances from the substituent. Copyright © 1999 John Wiley & Sons, Ltd.

KEYWORDS: silylation; substituent effect; *tert*-butyldimethylsilyl derivatives; benzhydroxamic acid; benzhydroximic acid; ^{13}C NMR; ^{15}N NMR; ^{29}Si NMR; chemical shifts

INTRODUCTION

Silylation of various OH and NH compounds has been used broadly as a tool in structure determination, exploiting the structurally sensitive ^{29}Si NMR shifts.[1] In silylation of the hydroxamic acids, the problem is not the structure of the parent compounds but of the products. Four mono-derivatives, **1–4**, are possible (Scheme 1; tautomers of **1** are not included) Of these, only **1** has been isolated,[2] although the structure was not strictly proven. Of the three possible bis-derivatives **5–7**, two were isolated from acethydroxamic acid: the originally claimed[3] structures **5** and **6** were reassigned[4] to **6** and **7**. The single isolated bis-derivative from benzhydroxamic acid was originally given[2,5] the structure **5**, but was recently recognized[6] as **6**. Structure **5** from benzhydroxamic acid is accessible by unambiguous synthesis[7] from *N,O*-bis(trimethylsilyl)hydroxylamine. Similarly, **5** and **6** (or **7**) were obtained together from substituted aliphatic hydroxamic acids.[8] Silylation thus proceeds differently to alkylation of hydroxamic acids. In typical experiments, **1** was always the single product of monoalkylation.[9] Further alkylation yielded a mixture of the *N*, *O*-bis-derivative **5** and the (*Z*)-O^1,O^4-bis-derivative **6**: their abundance varies strongly with the reaction conditions.[10] In other cases, the configuration of the C=N (**6** or **7**) was not determined,[11] or only one product was isolated,[12] sometimes of questionable structure.[9,13]

Evidently, the course of the silylation reaction depends strongly on the structure of the hydroxamic acid. Even remote substituents on the benzene rings can change certain properties of hydroxamic acids profoundly, e.g. the structure of their anion[14,15] or their crystal structure.[15] For this reason, in the present study we aimed to examine whether the substituents in the *meta* and *para* positions also affect the structure of the silylation product, i.e. whether **6** remains the only product. At the same time, it was of interest to follow substituent effects on selected NMR parameters, e.g. chemical shifts of different nuclei at different distances from the substituent. For technical reasons (greater stability against hydrolysis in prolonged experiments) we chose the *tert*-butyldimethylsilyl group as the silyl substituent, $T = Si(CH_3)_2C(CH_3)_3$ (Scheme 1).

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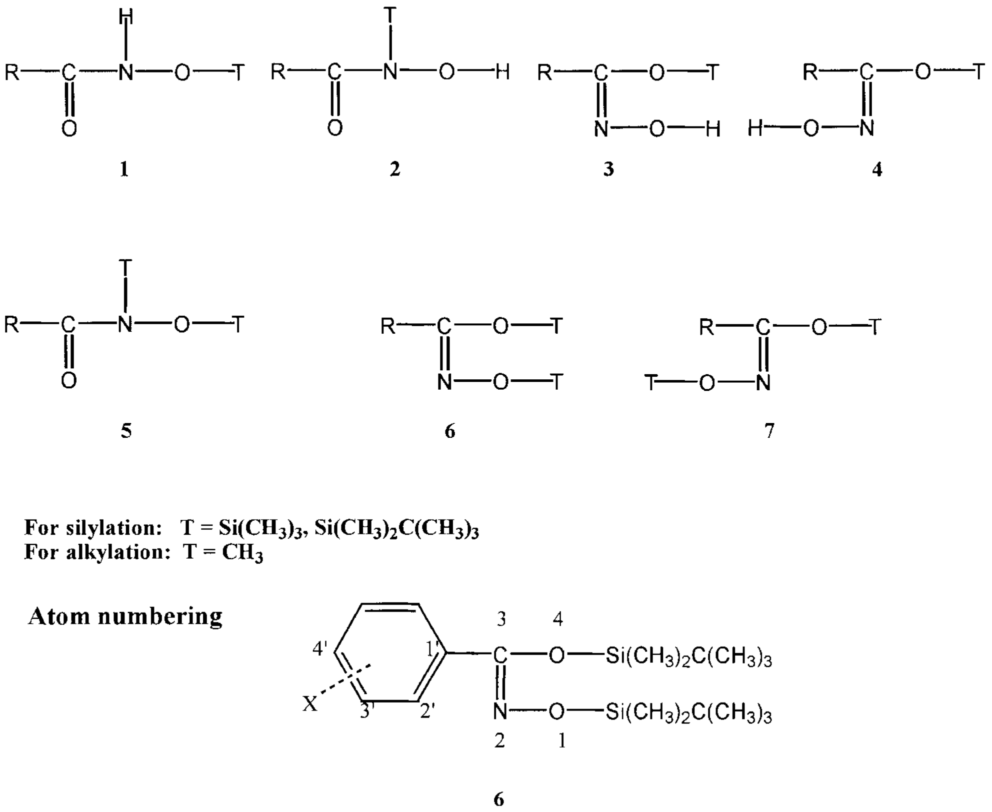
Contract/grant sponsor: Grant Agency of the Academy of Sciences of the Czech Republic; *Contract/grant number:* A 4072605.

CCC 0894–3230/99/090668–07 $17.50



For silylation: $T = Si(CH_3)_3$, $Si(CH_3)_2C(CH_3)_3$
For alkylation: $T = CH_3$

Scheme 1. Structures of hydroxamic acid derivatives

EXPERIMENTAL

The parent substituted benzhydroxamic acids were prepared by standard procedures as described elsewhere.[16] *tert*-Butyldimethylsilyl (TBDMS) derivatives of substituted benzhydroxamic acids were prepared by stirring the neat acid with a 2.6-fold excess of *N*-(*tert*-butyldimethylsilyl)-*N*-methyltrifluoroacetamide (MTBSTFA) with 1% of *tert*-butyldimethylsilyl chloride (Aldrich) in a closed flask at 100 °C for 4 h, followed by the removal of the unreacted reagent and other side-products under reduced pressure. The isolated compounds were identified and checked by ^{1}H and ^{13}C NMR spectroscopy. (^{1}H NMR spectra were not analyzed in terms of coupling constant and chemical shift values of aromatic protons; the splitting pattern was used to check the position of the substituent.)

The NMR spectra were measured in dry chloroform-*d* solutions containing 1% (v/v) of hexamethyldisilane (HMDSS) as a secondary reference. The reported (^{13}C and ^{29}Si) chemical shifts were obtained from diluted solutions. The concentration of the sample was reduced until the ^{13}C chemical shift of HMDSS was $\delta = -2.48 \pm 0.02$, relative to the central line of the solvent at 76.99 ppm (see Ref. 1 for the details of this standard procedure). A high sample concentration (ca 33%, v/v) was used in ^{15}N NMR and INADEQUATE measurements. ^{1}H, ^{13}C and ^{29}Si NMR spectral measurements were performed on a Varian UNITY-200 spectrometer (operating at 50.3 MHz for ^{13}C and at 39.7 MHz for ^{29}Si NMR measurements), ^{15}N spectra were measured on a Varian UNITY 500 spectrometer (at 50.667 MHz). In all cases the standard software (APT, INADEQUATE and INEPT pulse sequences) was used. The spectra were recorded in the temperature range 22–24 °C. The ^{29}Si NMR spectra were measured by the INEPT with the pulse sequence optimized[17] for TMS derivatives, i.e. for coupling to nine protons and a coupling constant of 6.5 Hz. The signal loss in the case of TBDMS derivatives was negligible.[17] Acquisition (2.0 s) was followed by a relaxation delay of 5 s. During the acquisition period WALTZ decoupling was used and FID data (16K) were sampled for a spectral width of 4000 Hz. Zero filling to 32K and a mild exponential broadening were used in the data processing. The ^{29}Si $\pi/2$ pulses were at the maximum 17 μs long whereas the ^{1}H $\pi/2$ pulses were 17 μs in a 5 mm switchable probe. The ^{29}Si spectra were referenced to the line of HMDSS at $\delta = -19.79$. The ^{13}C NMR spectra were measured using a spectral width of 16 000 Hz. WALTZ decoupling was applied during both acquisition (1 s) and relaxation delay (2–5 s). Zero filling to 64K and 1–3 Hz line broadening were used in data processing.

Aromatic carbon chemical shifts were assigned by a combination of additive increments (using the values from Ref. 18) and the shifts assigned for the parent (*Z*)-*O*-

Table 1. NMR parameters of substituted (*Z*)−*O*[1], *O*[4]-bis(*tert*-butyldimethylsilyl)-benzhydromimic acids, **6**[a]

Substituent X	$\delta(^{29}Si(O^1))$	$\delta(^{29}Si(O^4))$	$\delta(^{15}N)$[b]	$^1J(^{13}C,^{13}CN)$ (Hz)[b]
4-$N(CH_3)_2$	26.15	22.09	−83.7[c]	77.8
4-$NHSiMe_2CMe_3$	26.26	22.14[d]	−83.4[e]	—[f]
4-OCH_3	26.86	22.83	−81.8	76.9
4-CF_3	28.34	24.33	−73.5	75.5
4-NO_2	29.10	25.10	−70.5[g]	75.8
H	27.33	23.17	−78.0	75.2
4-CH_3	27.05	22.92	−79.3	—[f]
4-F	27.51	23.57	−79.5[h]	76.5
4-Cl	27.79	23.82	−77.4	—[f]
3-NO_2	28.86	25.16	−73.6[i]	76.9
3-OCH_3	27.40	23.26	−76.9	75.1
3-Cl	28.05	24.07	−75.3	75.7

[a] Unless indicated otherwise, the values of chemical shifts, on the δ scale, are from dilute solutions.
[b] Values from concentrated solutions.
[c] Other N at −330.3 ppm.
[d] Other Si at 8.11 ppm.
[e] Other N at −314.2 ppm.
[f] Not measured.
[g] Other N at −11.0 ppm.
[h] Line split in to a doublet by $J = 1.4$ Hz.
[i] Other N at −10.0 ppm.

trimethylsilyl trimethylsilylbenzohydroximate through a 2D INADEQUATE experiment.[19] It is noteworthy that the 2D INADEQUATE experiment when performed on similarly *para*-substituted aromatic rings could be misleading. In these compounds some of the coupled pairs of nuclei (C-1′ and C-2′; C-3′ and C-4′) have chemical shifts symmetrically disposed around the center of the aromatic region and the other pairs are strongly coupled. Hence, in the usual set-up of a 2D experiment, all the double-quantum coherences show up in the middle of the F_1 axis and can be easily mistaken for axial peaks or noise in the 2D spectrum.

Our attempts to assign experimentally the ^{13}C lines of TBDMS groups failed because the long-long range ^{13}C–^{13}C coupling constants involved are small and we were not equipped to perform ^{13}C–^{29}Si correlation experiments. However, a comparison with the shifts in the model, [6](*Z*)-*O*[4]-ethyl *tert*-butyldimethylsilylbenzhydroximate, δ ($^{13}C) = 18.14$, allowed us to assign tentatively the quaternary carbon line at a lower chemical shift value to the quaternary carbon in the TBDMS group bonded to O—N (O^1) in the studied compound with X = H. Since the shifts vary slowly with varying substituent and the shifts of the two quaternary carbons differ by at least 0.3 ppm, we tentatively extended this assignment to the whole series of studied compounds. Similar assignment of the methyl carbon lines was not possible as the shift in the model compound [$\delta(^{13}C) = 26.16$] was in the middle between the shifts observed in the bis(*tert*-butyldimethylsilyl) derivative with R = H.

When a fluorine-containing substituent was present, the ^{13}C–^{19}F couplings were used to check the assignment of aromatic carbon lines. The surprising ^{19}F–^{15}N coupling across six bonds, observed in the ^{15}N NMR spectrum of the *p*-fluoro derivative, was verified by repeated measurements with internal nitromethane used as a lineshape standard.

Coupling constants $^1J(^{13}C, ^{13}CN)$ were determined by 1D INADEQUATE[20] experiments performed on the concentrated solutions using an acquisition time of 2 s.

RESULTS AND DISCUSSION

Structure determination

The determined NMR parameters are summarized in Tables 1 and 2. In a recent paper[6] we demonstrated that the product of silylation of the parent benzhydroxamic acid (X = H) is the (*Z*)-*O*[1],*O*[4]-disilyl derivative of benzhydroximic acid, **6** [both for $T = Si(CH_3)_2\,C(CH_3)_3$ and $T = Si(CH_3)_3$]. The benzhydroximic structure followed from the ^{29}Si chemical shifts, which showed that each of the two silicon atoms is bonded to an oxygen atom. The configuration (*Z*) was deduced from the values of $^1J(^{13}C, ^{13}CN)$ coupling constants in the silylation product and in model compounds with defined configuration. Supporting evidence came from the ^{15}N chemical shift, which in the silylation product is shifted some 120 ppm downfield from the shift in the parent hydroxamic acid. Moreover, the ^{13}C chemical shift of C═N is about 10 ppm upfield from the shift of the C═O carbon. In all the compounds studied here the ^{29}Si, ^{15}N and ^{13}C (C═N) chemical shifts have values close to those in the compound with X = H, and changes in these

Table 2. ^{13}C NMR chemical shifts in substituted (*Z*)−*O*^{1}, *O*^{4}-bis(*tert*-butyldimethylsilyl)benzhydroximic acids, **6**[a]

Substituent X	C=N	C-1′	C-2′	C-3′	C-4′	C-5′	C-6′	CH_3	C	CH_3Si
4-$N(CH_3)_2$[b]	153.36	120.85	127.44	111.43	151.24	111.43	127.44	26.52/26.09	19.04/18.63	−3.22/−4.92
4-$NHSiMe_2CMe_3$[c]	153.24	122.33	127.53	115.86	149.14	115.86	127.53	26.51/26.33	19.03/18.62	−3.18/−4.27
4-OCH_3[d]	152.81	125.71	127.76	113.37	160.62	113.37	127.76	26.47/25.98	19.01/18.61	−3.20/−4.93
4-CF_3[e]	151.95	136.72	126.48	125.03	131.14	125.03	126.48	26.39/25.91	18.96/18.59	−3.18/−4.97
4-NO_2	151.53	139.44	126.94	123.37	148.32	123.37	126.94	26.34/25.88	18.94/18.58	−3.16/−4.98
H	152.92	133.18	126.29	128.00	129.39	128.00	126.29	26.46/25.96	19.01/18.61	−3.17/−4.93
4-CH_3[f]	153.05	130.37	126.25	128.71	139.40	128.71	126.25	26.46/25.96	19.00/18.61	−3.22/−4.94
4-F[g]	152.23	129.32	128.18	114.98	163.60	114.98	128.18	26.43/25.94	18.97/18.60	−3.18/−4.96
4-Cl	152.22	131.73	127.56	128.25	135.36	128.25	127.56	26.41/25.92	18.96/18.58	−3.20/−4.97
3-NO_2	151.17	135.19	121.3	148.24	123.96	129.04	131.83	26.36/25.88	18.92/18.58	−3.19/−4.98
3-OCH_3[h]	152.76	134.57	111.33	159.25	115.54	129.02	118.81	26.44/25.95	18.99/18.60	−3.18/−4.95
3-Cl	151.91	135.09	126.4	134.01	129.38[d]	129.28[d]	124.37	26.40/25.91	18.94/18.57	−3.21/−4.96

[a] The values of chemical shifts on the δ scale are from dilute solutions.
[b] 40.31 ppm, CH_3N.
[c] 26.03 ppm, CH_3; 17.94 ppm, C; −4.92 ppm, CH_3Si.
[d] 21.33 ppm, CH_3.
[e] ^1J(C,F) = 272.0, ^2J(C,F) = 32.7, ^3J(C,F) = 3.9, ^4J(C,F) = 0 Hz, δ (CF_3) = 124.06 ppm.
[f] 55.16 ppm, CH_3.
[g] ^1J(C,F) = 249.0, ^2J(C,F) = 21.5, ^3J(C,F) = 8.3 and ^4J(C,F) = 2.9 Hz.

values follow reasonable dependences on the nature of the substituent, to be discussed below. The values of $^1J(^{13}C, ^{13}CN)$, which do not exhibit an obvious dependence on the substitution, lie within 2.5 Hz from the values found in R = H derivative. They are 1.1–3.7 Hz larger than the value found in the model compound with *Z* configuration (which has the coupling another 7 Hz larger than that found in the model with *E* configuration).[6] One can conclude that all these compounds have the same structure (and configuration) of the (*Z*)-*O*^{1}, *O*^{4}-bis-derivative **6**. For analogous reasons we extend the assignment[6] of ^{29}Si NMR lines [i.e. low-field line to Si(O^1) and high-field line to Si(O^4) in the compound with X = H)] to all the compounds studied here.

The ^{29}Si NMR spectra of some silylation products measured in concentrated solutions revealed the presence of some silicon-containing impurity, but the amount never exceeded 5% (and was usually much less) of the main product listed in Tables 1 and 2. The impurity presented itself as a pair of weak ^{29}Si lines of equal intensity and shifted by 0.1–0.4 ppm to high field from the lines of the main product. As we were not able to isolate and identify them fully, we can therefore speculate that these side-products are the *E* isomers **7**. (In the case of trimethysilylation of acetohydroxamic acid, which produced the two isomers in comparable amounts, the lines of the *E* isomer were shifted by −0.58 and 1.36 ppm from the low-and high-field lines of the *Z* isomer, respectively.[4] Different shift differences between the isomers in benzene derivatives can be caused by magnetic anisotropy of the benzene ring.) In conclusion, we accept the presence of minute amounts of **7** as being possible, and we can exclude the presence of the *N*,*O*-isomer **5** in detectable amounts.

The formation of benzhydroximic acid derivatives reported here might be related to the properties of the silylation reagent, MTBSTFA, which is known to silylate enolizable carbonyl groups.[21] However, other workers have reported silylated hydroximic acids as products of much milder silylation of hydroxamic acids by hexamethyldisilazane.[3,4,22]

The different course of the reaction as compared with alkylation can be attributed mainly to steric effects. Even in the alkylation reaction, the amount of *N*,*O*-dialkyl derivative decreases with increasing size of the alkyl group:[10] in the case of the bulky *tert*-butyldimethylsilyl group the amount of **5** can decrease to an undetectable level. On the other hand, the *N*-silyl derivative **5** could always be relatively less stable than the corresponding *N*-alkyl derivative as a consequence of the low energy of the N—Si bond.[23] Although this bond energy is not exactly constant, it is ca 160 kJ mol^{-1} lower than the O—Si bond energy;[24] the corresponding difference between the N—C and O—C bonds is only 40 kJ mol^{-1}.

Substituent-induced chemical shifts

The chemical shifts of ^{29}Si, ^{15}N and ^{13}C nuclei were correlated with various reactivity parameters derived from the reactivity[25] or directly from NMR shifts.[26] In Table 3 we give only the most significant results. We are aware that our series of compounds is not sufficiently large to provide sufficient results to draw conclusions about the substituent dependence of the individual shifts. However, in most cases it is sufficient for comparison with other series and for discussing the proportionality constants. The compound with the substituent $NHSi(CH_3)_2\ C(CH_3)_3$ was obtained as a byproduct. Its NMR shifts could be included only in correlations with other shifts or with the constants $\sigma_{m,p}$ since the constant σ_p could be estimated.

Table 3. Statistics of the correlations of substituent-induced shifts in hydroximic acid derivatives **6**

No.	Response function	Explanatory variables	Regression coefficients[a]	SD[b]	*R*[b]	*N*[b]
1	δ^{29}Si(O^1)	$\sigma_{m,p}$	1.83(9)	0.15	0.988	12
2	δ^{29}Si(O^1)	σ_F, σ_R	2.03(14), 2.24(13)	0.084	0.997	8[c]
3	δ^{29}Si(O^4)	$\sigma_{m,p}$	1.96(13)	0.22	0.977	12
4	δ^{29}Si(O^4)	σ_F, σ_R	2.35(10), 2.11(9)	0.058	0.999	8[c]
5	δ^{29}Si(O^4)	δ^{29}Si(O^1)	1.08(3)	0.10	0.995	12
6	δ^{13}C(=N)	$\sigma_{m,p}$	−1.29(16)	0.27	0.927	12
7	δ^{13}C(=N)	σ_F, σ_R	−2.01(8), −0.91(8)	0.050	0.998	8[c]
8	δ^{13}C(=N)	B^p, C^p[d]	−2.06(8), −0.09(3)	0.049	0.998	8[c]
9	δ^{13}C(=N)	δ^{13}C(=N)[e]	0.67(5)	0.15	0.981	8[c]
10	δ^{15}N	$\sigma_{m,p}$	7.89(63)	1.05	0.969	12
11	δ^{15}N	σ_F, σ_R	6.8(18), 12.2(16)	0.96	0.977	8[c]
12	δ^{15}N	D^p, E^p[d]	11.4(10), −1.8(5)	0.62	0.992	8[c]
13	δ^{13}C(1′)	$\sigma_{m,p}$	10.9(1.2)	1.93	0.948	12
14	δ^{13}C(1′)	σ_F, σ_R	5.0(9), 19.8(8)	0.55	0.997	8[c]
14	δ^{13}C(1′)	δ^{13}C(1)[f]	1.09(2)	0.28	0.999	6[c]
16	δ^{13}C(4′)	δ^{13}C(4)[f]	1.007(16)	0.41	0.999	6[c]
17	δ^{13}C(SiO^4)[g]	$\sigma_{m,p}$	−0.071(8)	0.014	0.939	12
18	δ^{13}C(SiO^1)[g]	$\sigma_{m,p}$	−0.033(6)	0.008	0.899	12
19	δ^{13}C(SiO^1)[g]	δ^{13}C(SiO^4)[g]	0.46(5)	0.006	0.953	12
20	δ^{13}C[h]	$\sigma_{m,p}$	−0.109(6)	0.010	0.985	12
21	δ^{13}C[i]	$\sigma_{m,p}$	−0.197(48)	0.079	0.795	12

[a] Standard deviation in parentheses.
[b] Standard deviation from the regression, correlation coefficient and number of observations, respectively.
[c] Only *para* substituents.
[d] Components of PCA.[26]
[e] Compounds ArCH=NC$_6$H$_5$.[35]
[f] Compounds ArCH=NCH$_2$C$_6$H$_5$.[36]
[g] Quaternary carbon.
[h] Not assigned methyl carbons of *tert*-butyl groups at higher shift values.
[i] Not assigned methyl carbons of *tert*-butyl groups at lower shift values.

The ^{29}Si shifts are most important. The data in Table 3, lines 1 and 3, confirm that these shifts are relatively sensitive to substitution and behave regularly, i.e. they follow the naive expectations for the dependence of the chemical shift on the assumed electron density as expressed by the Hammett constants,[27] σ_p, Eqn. (1):

$$\delta = \delta^\circ + \rho\sigma_{m,p} \tag{1}$$

The slopes for Si(O^1) and Si(O^4) chemical shifts are not significantly different despite the fact that Si(O^4) is one bond closer to the substituent. However, a direct correlation between the two chemical shifts (Table 3, line 5) reveals slightly greater sensitivity of Si(O^4) towards substituent effects. This close mutual correlation of the two ^{29}Si nuclei also indicates that the NMR shifts are controlled by some subtle effects not included in any reactivity parameter σ. As expected, the slopes (lines 1 and 3) are much smaller than those found in similar dependences in substituted phenlytrimethylsilanes (2.7)[28] and phenoxytrimethylsilanes (4.8).[29] This type of dependence was observed on the terminal nuclei at a distance from the substitution and not directly conjugated, for instance on ^{13}C(H$_3$) in the COOCH$_3$ group.[30]

The fit can be somewhat improved by dual substituent parameter (DSP) treatment,[25] Eqn. (2) (see Table 3, lines 2 and 4):

$$\delta = \delta^\circ + \rho_F\sigma_F + \rho_R\sigma_R \tag{2}$$

However, the improvement is merely apparent and is due mainly to the necessary restriction on *para* substituents. (The number of our *meta* substituents is too small for a separate correlation.) The proportionality constants for σ_F and σ_R do not differ significantly from each other, hence separation into σ_F and σ_R has not helped and one could use the constants σ_p, equal to the sum $\sigma_F + \sigma_R$.

The ^{13}C shifts within the C=N group are characterized by negative slopes of their dependences on substituent constant, as found similarly in all compounds with a multiple bond adjoining the benzene ring (in DSP treatment at least the slopes at the inductive term are negative).[26] Negative slopes in these correlations (as in Table 3, lines 6–8) were interpreted by a model in which the double bond behaves as an isolated unit polarized by the distant substituent.[31,32] In this way, a charge can arise at the position nearer to the substituent. Traditional DSP treatment[32] (Table 3, line 7) yields a good fit but the negative value of σ_R is not easy to explain within the framework of the above model. We undertook[26] instead a pricipal component analysis (PCA) of eight long series: its superiority over DSP was particularly in differentiating *meta* and *para* derivatives. The fit we obtained here with the components determined by PCA [Eqn. (3)] (Table 3, line 8)

$$\delta = \delta^{\circ} + \beta B^{p} + \gamma C^{p} \tag{3}$$

is not better than in DSP (line 7): there is only a simplification that in the PCA the components are not given any physical meaning. The difference between DSP and our PCA could be seen only in a comparison with *meta* derivatives, which are not available in sufficient number. In Table 3, line 9, the ^{13}C shifts are compared directly with the most similar reaction series found in the literature, substituted benzalbenzylamine,[33] $ArCH{=}NCH_2C_6H_5$. The correlation is not particularly good, confirming the PCA results[26] that the behavior of various series cannot be described by one parameter.

The above analysis applies also to ^{15}N shifts. This atom represents the opposite end of the C=N double bond and according to the above model the substituent shifts of ^{15}N=C nitrogen should be in the opposite direction than those of ^{13}C=N carbon. Table 3, lines 10–12, confirms this. In this case, correlation with PCA components[26] is much better than with DSP. In general, the PCA components derived solely from NMR shifts should give a better correlation than σ_F and σ_R. Note, however, that the D^p and E^p-components[26] were derived from compounds with a C=C bond only and apply excellently to C=N studied here. About as good as DSP is also the simple correlation with $\sigma_{m,p}$; its slope (7.9) fits nicely between those in analogous correlations holding for benzamides (4.5) and benzonitriles (10.5) as calculated from the data in Ref. 34.

The problem of aromatic carbon chemical shifts was analyzed many times with the approximate results that the shifts in the four positions, *ipso*, *ortho*, *meta* and *para*, are controlled by different factors and have almost nothing in common.[34,35] Our rather small series cannot contribute significantly to this problem. We attempted only a correlation with the ^{13}C shifts reported[36] for a closely related series of substituted benzalanilines, $ArCH{=}NC_6H_5$ (Table 3, lines 14 and 16). As expected, the correlation is very good and the slope is near to unity.

We could assign only tentatively the chemical shifts of the central carbons of the *tert*-butyl groups and not for any of the methyl carbons of the TBDMS groups. However, since the latter fall into distinct series of values, it seems safe to assume that each of the series is due to one type of the methyl group and hence, although not assigned, can be correlated with the substituent constants. While the shifts of CH_3Si carbon atoms do not exhibit any correlation with $\sigma_{m,p}$, carbon atoms of the methyl groups from the *tert*-butyl groups show such correlations despite the fact that they are even further remote from the substituent. Moreover, the negative slopes are in absolute value larger in these correlations than the similarly negative slopes in the correlations that hold for the assigned central quaternary carbon atoms of the *tert*-butyl groups. The most direct proof of the existence of a substituent effect is the mutual correlation between the chemical shifts of the two quaternary carbons (Table 3, line 19); its standard deviation is below the experimental error.

On pure aliphatic side-chains, an alteration of the sign of ρ was observed together with strong attenuation:[37] on the third atom the substituent effect was already negligible. An observable substituent effect on the fourth, fifth, and sixth atoms from the benzene ring is unique, evidently the electron-attracting group C=N is important in addition to the polarizable O—Si linkage.

CONCLUSIONS

Exhaustive silylation of substituted benzhydroxamic acids yields only one product indepently of substitution. The products, (*Z*)-*O*^{1},*O*^{4}-bis(*tert*-butyldimethylsilyl) derivatives of substituted benzhydroximic acids, served as good models for studying the substituent-induced NMR shifts. Of the dependences observed, those of distant ^{13}C atoms deserve particular attention.

Acknowledgements

This work was supported by grant A 4072605 from the Grant Agency of the Academy of Sciences of the Czech Republic.

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