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Formation of *N,N′*-Disubstituted Methanediamine Derivatives from Hexamethyldisilazane and Aldehydes via Stepwise Reactions

Kozaburo Nishiyama,* Masaki Saito, and Makoto Oba
Department of Chemistry, Tokyo Metropolitan University, 2-1-1, Fukasawa, Setagaya, Tokyo 158
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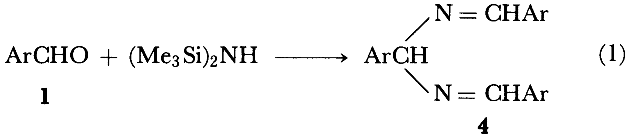
Synopsis. The $ZnCl_2$-catalyzed reaction of aldehydes with hexamethyldisilazane (HMDS) resulted in the formation of *N,N′*-disubstituted methanediamines, which were found to be formed stepwisely via 1 : 1- and 1 : 2-adducts of HMDS and aldehydes.

Although alkali metal salts of hexamethyldisilazane (HMDS) are well-known to be hindered bases for organic synthesis, only a few reports concerning the synthetic utility of disilazane itself can be found in the literature. Recently, two groups[1] reported the introduction of an amino moiety into organic molecules by using HMDS; the conversion of acyl halides into amides. On the other hand, we have been interested in the reactivity of a variety of Si-N bond of organosilicon compounds, e.g. silyl azide,[2] silyl isocyanate,[3] and silyl isothiocyanate.[4] As a continuation of our work in this area, the $ZnCl_2$-catalyzed reaction of aldehydes (**1**) with hexamethyldisilazane (HMDS), having two reactive Si-N bonds in a molecule, was investigated and we now report our results in this paper.

Results and Discussion

Treatment of benzaldehyde (**1a**) with 2 equiv of HMDS and a catalytic amount of $ZnCl_2$ in dichloromethane at room temperature for 24 h resulted in the formation of colorless needles (hexane), mp 100—101 °C, which were identified as *N,N′*-dibenzylidenephenylmethanediamine (**4a**). Without zinc chloride or in hexane, the reaction between benzaldehyde and HMDS did not proceed at all and starting materials were quantitatively recovered. When the reaction was interrupted in 1 h, the sole product was **4a** in a low yield (16%). Analogously, four *N,N′*-bis(arylmethylene)arylmethanediamines (**4b**—**e**) were obtained from the corresponding aromatic aldehydes (Eq. 1 and Table 1). On the other hand, Duffaut and Dupin reported that the treatment of ketones and benzaldehyde with silazanes [$(Me_3Si)_2NR$; R=H and Me] and silyl amines ($Me_3SiNHPh$ and Ph_3SiNH_2) in the presence of Zn/Cd at 165 °C for 40 h gave the corresponding imines (>C=NR; R=H, Me, and Ph) in yields of 30—95%.[5]



$$\underset{\mathbf{1}}{ArCHO} + (Me_3Si)_2NH \longrightarrow \underset{\mathbf{4}}{ArCH(N{=}CHAr)_2} \qquad (1)$$

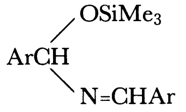
a, Ar=Ph, **b**, Ar=*p*-$MeOC_6H_4$, **c**, Ar=*p*-MeC_6H_4,
d, Ar=*p*-CNC_6H_5, **e**, Ar=*p*-$NO_2C_6H_4$

With *p*-cyanobenzaldehyde (**1d**), a trace amount of *N*-(*p*-cyanobenzylidene)-1-(*p*-cyanophenyl)-1-(trimethylsiloxy)methanamine (**3d**) with **4d** (46%) was isolated by fractional recrystallization from benzene and hexane. Since compound **3d** could be a precursor of **4d**, the reaction of **1d** with HMDS was again carried out for 10 h at room temperature. Consequently, compounds **3d** and **4d** were obtained in 23 and 32% yields, respectively. Similarly, the treatment of **1e** with HMDS for 24 h afforded a mixture of **3e**, which was too unstable to be fully characterized, and **4e** (30%). An attempt to separate the mixture by column chromatography on alumina (eluent; $CHCl_3$) gave *p*-nitrobenzylideneamino-*p*-nitrophenylmethanol (**3e′**).

Table 1. $ZnCl_2$-Induced Reaction of Carbonyl Compound with HMDS

Carbonyl compd	Product	(Yield/%)	Mp θ_m (bp θ_b)/°C
1a		(0)[a]	
1a	**4a**	(16)[b]	100—101
1a	**4a**	(79)	
1b	**4b**	(66)	128—129
1c	**4c**	(73)	93—94
1d[c]	**3d**	(23)	117
	4d	(32)	122—124
1d	**4d**	(46)	
1e	**4e**	(30)	140 (decomp)
t-BuCHO (**1f**)	**4f**	(42)	(173/2 mmHg)
cyclo-$C_6H_{10}O$ (**1g**)	**4g**	(53)	(163/2 mmHg)
Cl_3CCHO (**1h**)	**2h**	(70)	(80—82/4 mmHg)

a) Without $ZnCl_2$. b) Stirred for 1 h. c) Stirred for 10 h.



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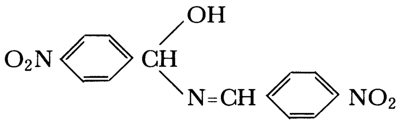
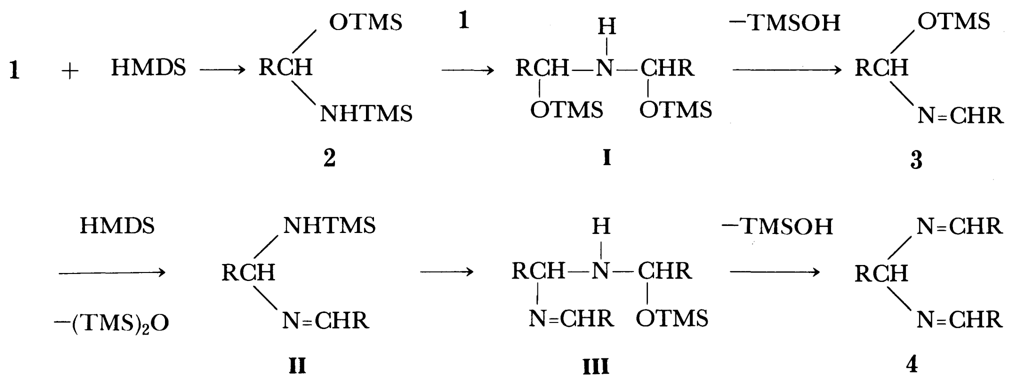


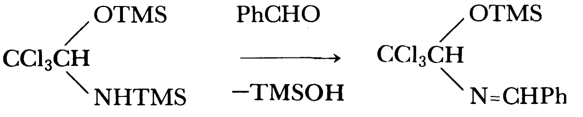
3e′

From these findings, it is clear that the formation of **4** involves stepwise reactions which must proceed via **3** and that an electron-withdrawing group of the aldehyde would retard either step(s) of the successive reactions. More remarkably, in cases of aliphatic aldehydes, the product was dependent upon an electronic rather than a steric effect of the alkyl group. With 2,2-dimethylpropanal (**1f**) and cyclohexanone (**1g**), *N,N′*-bis(2,2-dimethylpropylidene)-2,2-dimethyl-1,1-propanediamine (**4f**) and *N,N′*-dicyclohexylidene-1,1-cyclohexanediamine (**4g**) were produced in 42% and 53% yields,[6] respectively, as a sole product, whereas only a 1 : 1-adduct of trichloroethanal (**1h**) and HMDS, *N*-trimethylsilyl-1-trimethylsiloxy-2,2,2-trichloroethanamine (**2h**), was obtained in a 70% yield. The treatment of **2h** with benzaldehyde under similar conditions gave *N*-benzylidene-1-trimethylsiloxy-2,2,2-trichloroethanamine (**3h′**) in a 53% yield. As to this



Scheme

reaction course, it was postulated that the addition of the remaining Si-N bond in **2h** to benzaldehyde followed by the elimination of trimethylsilanol occurred to give **3h′** (Eq. 2).



$$CCl_3CH(OTMS)(NHTMS) \xrightarrow[-TMSOH]{PhCHO} CCl_3CH(OTMS)(N{=}CHPh) \quad (2)$$

2h **3h′**

On the basis of the above results, we suggest the reaction pathway shown in the Scheme to account for the formation of the *N,N′*-bis(arylmethylene)arylmethanediamines **4** from aldehyde with HMDS. The first and second steps are $ZnCl_2$-induced addition reactions of Si-N bonds to the carbonyl group of the aldehyde, giving the 1 : 1-adduct **2** and 1 : 2-adduct **I**, respectively. Furthermore, the latter undergoes the elimination of trimethylsilanol to produce *N*-benzylidenephenylmethane derivative **3**. Condensation of **3** with HMDS gives hexamethyldisiloxane and the diamino intermediate **II**; **II** adds to another aldehyde to give the adduct **III**, which would be subjected to the further elimination of trimethylsilanol, giving the final product **4**. The conversion step of **3** into **II** finds analogy in another study of ours; in which *gem*-diazides were found to be isolated via α-siloxy azides from the similar reaction of aldehydes[2] and ketones[7] with silyl azide. For these reactions, an electron-withdrawing group of aldehydes retards the addition process and compounds **4** having an electron-donationg group were obtained in higher yields under the conditions employed.

Compound **4** is important as an intermediate for trisubstituted imidazole derivatives; the dehydrogenation of *N,N′*-dibenzylidenephenylmethanediamine gives 2,4,5-triphenyl-1*H*-imidazole.[8]

Experimental

Melting points are uncorrected. Infrared spectra were measured on a Hitachi 260-10 infrared spectrometer. ^{1}H NMR spectra were determined with a Hitachi R-600 using tetramethylsilane as an internal standard. Mass spectra (MS) were obtained using a JEOL DX-300 spectrometer.

Hexamethyldisilazane (HMDS) and aldehydes were commercial products and were purified by distillation or recrystallization if necessary.

$ZnCl_2$-Induced Reaction between Aldehyde (1a—1f) and HMDS. General Procedure. A suspension of aldehyde (30 mmol), HMDS (60 mmol), and $ZnCl_2$ (6 mmol) in CH_2Cl_2 (30 cm^3) was stirred for 24 h at room temperature. The reaction mixture was poured into water (30 cm^3) and dichloromethane (30 cm^3). Extraction with three 30 cm^3 portions of dichloromethane followed by washing with water completed the work-up. The extract was dried over anhydrous $MgSO_4$ and concentrated in vacuo. The resulting mixture was triturated with hexane (for **4a—4d**) or benzene (for **4e**) and the precipitated solid was collected by filtration. The solid was recrystallized from an appropriate solvent (hexane, a mixture of hexane and benzene, or acetonitrile). When the product was liquid (**4f** and **4g**), it was directly distilled under reduced pressure. The yields of products are listed in Table 1. Spectral and physical data are as follows.

4a: colorless needles (hexane); mp 100—101 °C (lit,[9] 100 °C). IR (KBr) ν 1625 (C=N) cm^{-1}. MS *m/z* 194 (M^+ −N=CHPh). ^{1}H NMR ($CDCl_3$) δ=5.93 (s, 1H), 7.20—7.89 (m, 15H), and 8.51 (s, 2H). **4b**: colorless needles (hexane); mp 128—129 °C IR (KBr) ν 1620 (C=N) cm^{-1}. MS *m/z* 254 (M^+−N=$CHC_6H_4OCH_3$-*p*). ^{1}H NMR ($CDCl_3$) δ=3.75 (s, 3H), 3.81 (s, 6H), 5.80 (s, 1H), 6.84, 7.38 (ABq, 4H), 6.86, 7.74 (ABq, 8H), and 8.40 (s, 2H). Found: C, 74.15; H, 6.30; N, 7.20%. Calcd for $C_{24}H_{24}N_2O_3$: C, 74.21; H, 6.23; N, 7.21%. **4c**: colorless powder (hexane); mp 93—94 °C. IR (KBr) ν 1620 (C=N) cm^{-1}. MS *m/z* 222 (M^+−N=$CHC_6H_4CH_3$-*p*). ^{1}H NMR ($CDCl_3$) δ=2.32 (s, 3H), 2.40 (s, 6H), 5.87 (s, 1H), 7.13, 7.35 (ABq, 4H), 7.16, 7.68 (ABq, 8H), and 8.45 (s, 2H). Found: C, 84.96; H, 7.43; N, 8.01%. Calcd for $C_{24}H_{24}N_2$: C, 84.67; H, 7.11; N, 8.23%. **4d**: pale yellow powder (1 : 1 mixture of benzene and hexane), mp 122—124 °C. IR (KBr) ν 2210 (C≡N) and 1625 (C=N) cm^{-1}. MS *m/z* 244 (M^+−N=CHC_6H_4CN-*p*). ^{1}H NMR ($CDCl_3$) δ=6.06 (s, 1H), 7.62 (s, 8H), 7.67, 7.92 (ABq, 4H), and 8.53 (s, 2H). Found: C, 77.43; H, 4.24: N, 18.96%. Calcd for $C_{24}H_{15}N_5$: C, 77.20; H, 4.05; N, 18.75%. The mother liquor of **4d** was concentrated in vacuo and the residual solid was recrystallized from hexane, giving colorless needles, **3d**, mp 116—117 °C. IR (KBr) ν 2200 (C≡N), 1630 (C=N), and 1060 (Si-O-C) cm^{-1}. MS *m/z* 204 (M^+ −N=CHC_6H_4CN-*p*). ^{1}H NMR ($CDCl_3$) δ=0.20 (s, 9H), 6.30 (s, 1H), 7.57 (s, 4H), 7.66, 7.83 (ABq, 4H), and 8.50 (s, 1H). Found: C, 68.50; H, 5.85; N, 12.53%. Calcd for $C_{19}H_{19}N_3OSi$: C, 68.44; H, 5.74; N, 12.60%. **4e**: pale yellow plates (acetonitrile), mp 140 °C (decomp). IR (KBr) ν 1625 (C=N) and 1505, 1340 (NO_2) cm^{-1}. MS *m/z* 283 (M^+ −N=$CHC_6H_4NO_2$-*p*). Found: C, 58.23; H, 3.44; N, 15.98%. Calcd for $C_{21}H_{15}N_5O_6$: C, 58.20; H, 3.49; N, 16.16%. The ^{1}H NMR spectrum of **4e** could not be determined because the isolated **4e** did not disolve in $CDCl_3$ and CD_3CN and decomposed in DMSO-d_6. **3e′**: pale yellow powder ($CHCl_3$), mp 203—204 °C. IR (KBr) ν 3275 (OH), 1635 (C=N), and 1500, 1340 (NO_2) cm^{-1}. MS *m/z* 301 (M^+). Found: C, 55.40; H, 3.62; N, 14.00%. Calcd for $C_{14}H_{11}N_3O_5$: C, 55.82%; H, 3.68; N, 13.95%. **4f**: colorless liquid, bp 173 °C/2 mmHg (1 mmHg=133.322 Pa.). IR (neat) ν 1660 (C=N) cm^{-1}. MS *m/z* 154 (M^+ −N=CHBu-*t*). ^{1}H NMR ($CDCl_3$) δ=0.89 (s, 9H), 1.09 (s, 18H), 3.83 (s, 1H), and 7.49 (s, 2H). **4g**: colorless liquid, bp 155—163 °C/2 mmHg. IR (neat) ν 1660 (C=N) cm^{-1}. MS *m/z* 274 (M^+). ^{1}H NMR ($CDCl_3$) δ=1.00—2.40 (m).

Reaction of Trichloroethanal (1h) with HMDS. A mixture of **1h** (4.42 g, 30 mmol), HMDS (9.69 g, 60 mmol), and $ZnCl_2$ (0.82 g, 6 mmol) in CH_2Cl_2 (30 cm^3) was stirred for 75 h at room temperature. Direct distillation of the reaction mixture gave a colorless oil, which boiled at 80—82 °C/4 mmHg and was assigned to **2h**, yield, 6.48 g (70%). IR (neat) ν 3380 (NH) and 1250 (C-$SiMe_3$) cm^{-1}. MS *m/z* 190 (M^+ −CCl_3). ^{1}H NMR ($CDCl_3$) δ=0.20 (s, 9H), 0.25 (s, 9H), 4.63 (s, 1H), and 4.85 (s, 1H). Found: C, 30.81; H, 6.59; N, 4.55%. Calcd for $C_8H_{20}Cl_3OSi_2$: C, 31.12; H, 6.53; N, 4.54%.

When the reaction between **1h** (11.08 g, 75 mmol) and HMDS (12.13 g, 75 mmol) in the presence of $ZnCl_2$ (2.05 g, 15 mmol) in CH_2Cl_2 (75 cm^3) was carried out for 24 h at room temperature, repeated distillation afforded a detrimethylsilylated compound **2h′** (1-trimethylsiloxy-2,2,2-trichloroethanamine) instead of **2h**, yield 6.12 g (35%). Bp 49—50 °C/4 mmHg. IR (neat) ν 3400 and 3300 (NH_2) and 1250 (C-$SiMe_3$) cm^{-1}. MS *m/z* 118 (M^+ −CCl_3). ^{1}H NMR ($CDCl_3$) δ=0.18 (s, 9H), 2.00 (s, 2H), and 4.60 (s, 1H). Found: C, 25.55; H, 5.15; N, 6.08%. Calcd for $C_5H_{12}Cl_3NOSi$: C, 25.38; H, 5.11; N, 5.92%.

Reaction of 2h with Benzaldehyde. A mixture of **2h** (5.26 g, 17 mmol), benzaldehyde (**1a**, 1.81 g, 17 mmol), and $ZnCl_2$ (0.46 g, 3.4 mmol) in CH_2Cl_2 (17 cm^3) was stirred for 24 h at room temperature. After usual work-up, direct distillation (bp 108 °C/2 mmHg) of the dried mixture gave a pale yellow liquid which was characterized to *N*-benzylidene-1-trimethylsiloxy-2,2,2-trichloroethanamine (**3h′**), yield 2.1 g (38%). IR (neat) ν 1635 (C=N) and 1250 (C-$SiMe_3$) cm^{-1}. MS *m/z* 206 (M^+ −CCl_3). ^{1}H NMR ($CDCl_3$) δ=0.35 (s, 9H), 5.61 (s, 1H), 7.40—7.96 (m, 5H), and 8.53 (s, 1H). Found: C, 44.49; H, 5.26; N, 4.35%. Calcd for $C_{12}H_{16}Cl_3NOSi$: C, 44.39; H, 4.97; N, 4.31%.

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