Notes

P(*i*-PrNCH₂CH₂)₃N: An Effective Lewis Base Promoter for the Allylation of Aromatic Aldehydes with Allyltrimethylsilane

Zhigang Wang, Philip Kisanga, and John G. Verkade*

Department of Chemistry, Iowa State University, Ames, Iowa 50011-3111

The allylation of carbonyl compounds with allylsilanes under Lewis acidic conditions has been extensively investigated owing to its importance in the formation of C−C bonds in organic synthesis.[1,2] Recently, the allylation of aldehydes with allylsilanes promoted by Lewis bases has also attracted considerable attention because of the mild reaction conditions and the high regio- and stereoselectivity encountered.[3,4] Allylsilanes used in these reactions, such as allyltrichlorosilane and allyltrifluorosilane, are easily activated by Lewis bases since the silicon atom bears strong electron-withdrawing groups, thereby facilitating smooth aldehyde allylations. However, we found only one report on the reaction of allyltrimethylsilane with aldehydes in the presence of a Lewis base promoter, namely, fluoride ion.[5] In that report, refluxing THF was required. In our continuing exploration of the synthetic utility of exceedingly strong nonionic bases of type **1** first synthesized in our laboratories,[6] we have discovered that **1a** and **1b** are very useful in a variety of both stoichiometric[7] and catalyzed reactions.[8] It is noteworthy that the strong basicity of bases of type

1a R = Me	H**1a**⁺
1b R = *i*-Pr	H2**b**⁺
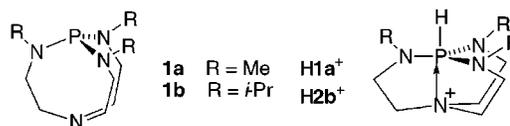
1 is due to transannular bonding that can occur as, for example, in the conjugate Lewis acids H**1a**⁺ and H**1b**⁺.[6] Here we report that Lewis base **1b** acts as a promoter for the allylation of a substantial number of aldehydes with allyltrimethylsilane at room temperature or 40 °C.

$$\text{2} + \text{R'CHO} \xrightarrow[\text{THF}]{\textbf{1b} \ (0.2 \ \text{equivalent})} \text{4} \quad (1)$$
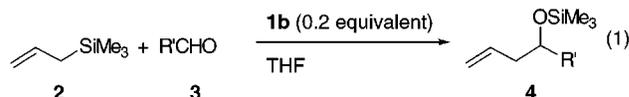
Initially, P(NMe₂)₃ (HMPT) and **1a** were chosen as candidate catalysts for comparison in the allylation of benzaldehyde with allyltrimethylsilane. However, HMPT showed no activity in this reaction, and only a trace of the corresponding homoallylic alcohol was observed in the complicated reaction mixture when **1a** was used. On the other hand, when **1b** (0.5 equiv) was employed, the desired homoallylic alcohol was isolated in 74% yield. The reaction was monitored by TLC which showed that the reaction was quite clean. A comparable yield of 72% was achieved even when the amount of **1b** was decreased to 0.2 equiv, but it dropped to 62% when the amount of **1b** was further decreased to 0.1 equiv. Thus, reaction 1 with a variety of aromatic aldehydes was investigated in the presence of 20 mol % **1b**, and the results are listed in Table 1.

As shown in this table, aldehydes bearing an electron-donating group possess lower reactivity. Hence, *p*-dimethylaminobenzaldehyde, *p*-methoxybenzaldehyde, and *p*-methylbenzaldehyde gave 44−57% yields even at 40 °C for extended time periods (entries 4−6). Except for *p*-fluorobenzaldehyde, which displayed considerable reactivity leading to a 77% yield (entry 7), some aldehydes bearing electron-withdrawing groups, such as *p*-Cl, unexpectedly showed reduced reactivity. When *p*-cyano- or *p*-nitrobenzaldehyde was added to a solution of **1b** in THF, no corresponding homoallylic alcohol was detected. However, the color of the reaction solution rapidly turned deep red in both cases, which is attributed to the

(1) (a) Hosomi, A.; Sakurai, H. *Tetrahedron Lett.* **1976**, *17*, 1295. (b) Tietze, L. F.; Schiemann, K.; Wegner, C.; Wulff, C. *Chem. Eur. J.* **1996**, *2*, 1164. (c) Gauthier, D. R.; Carreira, E. M. *Angew. Chem., Int. Ed. Engl.* **1996**, *35*, 2363.

(2) (a) Majetich, G. *Organic Synthesis, Theory and Application*; JAI Press: Greenwich, CT, 1989. For reviews see: (b) Yamamoto, Y. *Chem. Rev.* **1993**, *93*, 137. (c) Masse, C. E.; Panek, J. S. *Chem. Rev.* **1995**, *95*, 1293. (d) Cozzi, P. G.; Tagliavini, E.; Umani-Ronchi, A. *Gazz. Chim. Ital.* **1997**, *127*, 247. (e) Chan, T. H.; Wang, D. *Chem. Rev.* **1992**, *92*, 995.

(3) (a) Kira, M.; Hino, T.; Sakurai, H. *Tetrahedron Lett.* **1989**, *30*, 1099. (b) Kira, M.; Kobayashi, M.; Sakurai, H. *Tetrahedron Lett.* **1987**, *28*, 4081. (c) Kobayashi, S.; Nishio, K. *Tetrahedron Lett.* **1993**, *34*, 3453. (d) Kobayashi, S.; Nishio, K. *J. Org. Chem.* **1994**, *59*, 6620. For reviews on hypervalent silicates, see: (e) Sakurai, H. *Synlett* **1989**, 1. (f) Chuit, C.; Corriu, R. J. P.; Reye, C.; Young, J. C. *Chem. Rev.* **1993**, *93*, 1371.

(4) (a) Denmark, S. E.; Coe, D. M.; Pratt, N. E.; Griedel, B. D. *J. Org. Chem.* **1994**, *59*, 6161. (b) Iseki, K.; Kuroki, Y.; Takahashi, M.; Kobayashi, Y. *Tetrahedron Lett.* **1996**, *37*, 5149. (c) Iseki, K.; Kuroki, Y.; Takahashi, M.; Kishimoto, S.; Kobayashi, Y. *Tetrahedron* **1997**, *53*, 3513. (d) Wang, Z.; Wang, D.; Sui, X. *Chem. Commun.* **1996**, 2261. (e) Iseki, K.; Mizuno, S.; Kuroki, Y.; Kobayashi, Y. *Tetrahedron Lett.* **1998**, *39*, 2767. (f) Nakajima, M.; Saito, M.; Hashimoto, S. *J. Am. Chem. Soc.* **1998**, *120*, 6419.

(5) (a) Hosomi, A.; Shirahata, A.; Sakurai, H. *Tetrahedron Lett.* **1978**, *19*, 3043. (b) Asao, N.; Shibato, A.; Itagaki, Y.; Jourdan, F.; Maruoka, K. *Tetrahedron Lett.* **1998**, *39*, 3177.

(6) Verkade, J. G. *Acc. Chem. Res.* **1993**, *26*, 483.

(7) (a) Tang, J. S.; Verkade, J. G. *J. Org. Chem.* **1994**, *59*, 7793. (b) Mohan, T.; Arumugam, S.; Wang, T.; Jacobson, R. A.; Verkade, J. G. *Heteroatom Chem.* **1996**, *7*, 455. (c) Tang, J. S.; Verkade, J. G. *J. Org. Chem.* **1996**, *61*, 8750. (d) Arumugam S.; Verkade, J. G. *J. Org. Chem.* **1997**, *62*, 4827. (e) Arumugam, S.; Mcleod, D.; Verkade, J. G. *J. Org. Chem.* **1998**, *63*, 3677. (f) Wang, Z.; Verkade, J. G. *Tetrahedron Lett.* **1998**, *39*, 9331. (g) Wang, Z.; Verkade, J. G. *Heteroatom Chem.* **1998**, *9*, 687.

(8) (a) Tang, J. S.; Verkade, J. G. *Angew. Chem., Int. Ed. Engl.* **1993**, *32*, 896. (b) Tang, J. S.; Mohan, T.; Verkade, J. G. *J. Org. Chem.* **1994**, *59*, 4931. (c) D'Sa, B.; Verkade, J. G. *J. Org. Chem.* **1996**, *61*, 2963. (d) D'Sa, B.; Verkade, J. G. *J. Am. Chem. Soc.* **1996**, *118*, 12832. (e) D'Sa, B.; Mcleod, D.; Verkade, J. G. *J. Org. Chem.* **1997**, *62*, 5057. (f) D'Sa, B.; Kisanga, P.; Verkade, J. G. *J. Org. Chem.* **1998**, *63*, 3961. (g) Kisanga, P.; D'Sa, B.; Verkade, J. G. *J. Org. Chem.* **1998**, *63*, 10057. (f) Kisanga, P.; Verkade, J. G. *J. Org. Chem.* **1999**, *64*, 4298.

Scheme 1
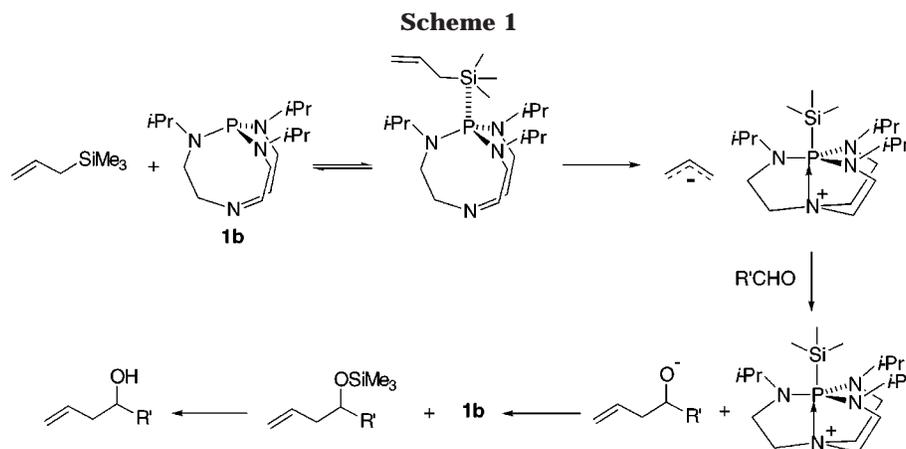
Table 1. Reactions of Aldehydes with Allyltrimethylsilane[a]

entry	**3,4** R'	reaction conditions		yield, %[b]
		T, °C	t, h	
1[c]	Ph	rt	72	74
2	Ph	rt	72	72
3[d]	Ph	rt	72	62
4	p-Me$_2$NC$_6$H$_4$	40	84	57
5	p-MeOC$_6$H$_4$	40	84	52
6	p-MeC$_6$H$_4$	40	84	44
7	p-FC$_6$H$_4$	rt	72	77
8	p-ClC$_6$H$_4$	rt	84	59
9	2-thiophenecarboxaldehyde	rt	72	80
10	2-furaldehyde	rt	72	73
11	2-naphthaldehyde	rt	72	73

[a] Reactions were carried out under argon in a ratio of **2:3:1b** = 1:1:0.2 mmol. THF was freshly distilled from Na and stored over 4 Å molecular sieves. [b] Homoallylic alcohol. [c] **2:3:1b** = 1:1:0.5. [d] **2:3:1b** = 1:1:0.1.

formation of a complex between **1b** and these aldehydes.[9] Both reaction mixtures were EPR silent, suggesting that an ionic complex is formed. This was further substantiated by ^{31}P NMR analysis in which only a ^{31}P signal associated with H**1b**$^+$ at −10.7 ppm was observed. In the reaction of *p*-cyanobenzaldehyde, an 81% yield of an epoxide was isolated.[10] The formation of epoxides in similar reactions has recently been observed in ourlaboratories and will be reported in due course.[10] The reaction of *p*-nitrobenzaldehyde, on the other hand, afforded a complicated reaction mixture although ^{31}P NMR spectroscopy revealed only a single peak at −10.7 ppm indicative of H**1b**$^+$ formation. As shown in Table 1, 2-thiophenecarboxaldehyde, 2-furaldehyde, and 2-naphthaldehyde gave respectable yields of product (entries 9−11).

The reaction of allyltrimethylsilane with aldehydes in the presence of **1b** is assumed to proceed in a manner similar to that of other allylation reactions promoted by Lewis bases.[5a] Thus, **1b** can be expected to coordinate with allyltrimethylsilane to form a pentacoordinate silicon species that also features a pentacoordinate phosphorus. The latter possibility, which would be achieved via at least partial N$_{ax}$ → P transannulation, receives support from an observation that HMPT does not promote this reaction under the same reaction conditions. One option for the reaction of the pentacoordinate allylsilicate with aldehyde is for silicon to coordi-

nate further with an aldehyde oxygen to form a hexacoordinate allylsilicate, thus allowing completion of this reaction through a six-membered ring transition state.[3a−c,4] Another possibility is that the C−Si bond of the pentaccordinate silicon intermediate cleaves to form an allylic anion, which then adds to the aldehyde to give α- or γ-addition products.[3a,b] To determine which pathway was followed, crotyltrimethylsilane (E:Z = 88:12)[11] was reacted with benzaldehyde under the same conditions listed in Table 1 (reaction 2). Although the reaction was very

(2)
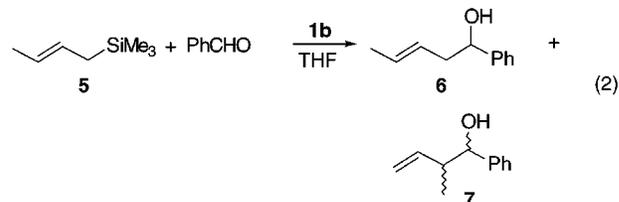
sluggish, both α- and γ-addition products in a ratio of 47:53[12] (**6** and **7**, respectively) were isolated as a mixture. For **7**, the *syn:anti* ratio was 48:52. This strongly suggests that an allylic anion was formed during the reaction as illustrated in Scheme 1. According to this scheme, **1b** coordinates with silicon to form a pentacoordinate allylsilicate intermediate probably featuring at least partial transannulation of the phosphorus cage. The Si−C bond is then broken, and an allylic anion is formed. The cationic intermediate which can then be stabilized by stronger transannulation is analogous to that characterized earlier by us in the silyl protection of alcohols catalyzed by **1a**.[8d,e] The allylic anion then reacts with the aldehyde to afford a silyl ether, thus releasing **1b** in completion of the catalytic cycle. The silyl ether is then finally hydrolyzed in workup to give the homoallylic alcohol. The relatively high yield of product in the case of *p*-FC$_6$H$_4$CHO compared with its *p*-NMe$_2$, *p*-OMe and *p*-Cl analogues (Table 1) is attributable to the greater +R effect of the latter substituents which is expected to reduce the electrophilicity of the carbonyl carbon to nucleophilic attack by the allyl group in what is probably the slow step. A similarly low product yield is expected from the hyperconjugation and the +I effect of the *p*-CH$_3$ group.

(9) Yang, J. C.; Verkade. J. G. Manuscript in progress.
(10) Liu, X.; Verkade, J. G. Manuscript in progress.

(11) (a) Hagen, G.; Mayr, H. *J. Am. Chem. Soc.* **1991**. *113*, 4954. (b) Alberts, V.; Cuthbertson, M. J.; Hawker, D. W.; Wells, P. R. *Org. Magn. Reson.* **1984**, *22*, 556.
(12) The ratio was determined by comparison of the ^{1}H NMR spectrum (300 MHz) of crude product with that in the literature (Takuda, M.; Satoh, S.; Suginome, H. *J. Org. Chem.* **1989**, *54*, 5608).

Experimental Section

Reactions were carried out under argon. THF was freshly distilled over sodium and stored over 4 Å molecular sieves under argon. The aldehydes (Aldrich) were used as received.

Typical Procedure for the Allylation. To a solution of **1b** (0.2 mmol) in dry THF (2 mL) was added the allyltrimethylsilane (1.0 mmol) by syringe at room temperature under argon. The reaction solution was then stirred at room temperature for 0.5 h followed by addition of the aldehyde (1.0 mmol). After the reaction conditions stated in Table 1 had been met, the reaction was quenched with saturated aqueous $NaHCO_3$ (3 mL) and ether (10 mL). The mixture was separated after stirring for 0.5 h, and the aqueous layer was further extracted with ether (3 × 20 mL). After the organic extracts were combined and dried with $MgSO_4$, the solvent was removed in a vacuum to afford the crude product. Purification of the crude product was achieved by flash chromatography (hexane:ethyl acetate = 30:1) to give the homoallylic alcohol.

Supporting Information Available: NMR spectral data for compounds in this study. This material is available free of charge via the Internet at http://pubs.acs.org.

JO990225W