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The search for tolerant Lewis acid catalysts. Part 1: Chiral silicon Lewis acids derived from (−)-myrtenal†

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Abstract

We have shown that association of a bulky silicon group with the bis(trifluoromethanesulfonyl)imide leaving group unexpectedly enhances the electrophilic character of the R_3SiNTf_2 silylating agent. The presence of a chiral substituent derived from (−)-myrtenal on the silicon atom led to a Lewis acid, which efficiently catalyzes the Diels–Alder reaction of α,β-unsaturated esters. Although not yet preparatively useful, the enantiomeric excesses (up to 54%) were the highest ever reported for a chiral silicon Lewis acid.

Keywords: Lewis acid; silylation; asymmetric Diels–Alder reaction.

We recently reported that many Lewis acids, which were shown to efficiently promote cycloadditions of simple dienes, could not be used for the catalysis of Diels–Alder reactions of 1- and 2-azadienes.[1] This probably resulted from competitive bindings of the Lewis acid by the diene and the dienophile. We recently showed that trimethylsilyl bis(trifluoromethanesulfonyl)imide, $TMSNTf_2$, was an efficient and tolerant catalyst for the Diels–Alder reaction of methyl acrylate with 2-azadienes and highly functionalized dienes as well as for representative ene reactions.[2] This initial study showed that $TMSNTf_2$ was much more electrophilic than TMSOTf which did not catalyze these reactions. This was confirmed and further illustrated by Simchen and Jonas who also prepared the corresponding triisopropylsilyl bis(trifluoromethanesulfonyl)imide, $TIPSNTf_2$.[3]

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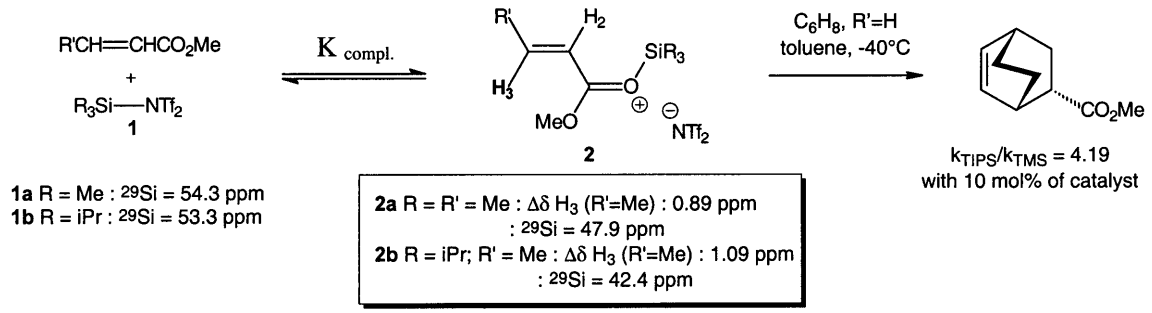
A comparative ^1H NMR study of the complexation of methyl crotonate[4] with various R_3SiNTf_2 reagents unexpectedly showed that $TIPSNTf_2$ *induced a higher downfield shift* of the H_3 proton signal of methyl *trans*-crotonate than $TMSNTf_2$ (Scheme 1). This suggested to us that bulkier groups on silicon favored the silylation of the carbonyl group. Confirmation of this surprising behavior came from the comparison of the catalytic efficiencies of **1a** and **1b** (10 mol%) on the cycloaddition of cyclohexadiene with methyl acrylate: *$TIPSNTf_2$ was found to be superior to $TMSNTf_2$* ($k_{TIPS}/k_{TMS} = 4.19$).

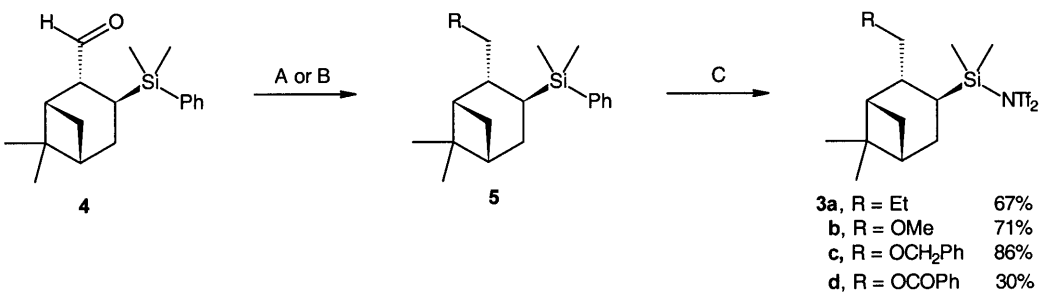


Scheme 1.

We found no convincing evidence[5] for the occurrence of a S_N1 type mechanism involving a solvated ion-pair in the case of the bulky $TIPSNTf_2$ catalyst. A more probable interpretation of this surprising observation is that the higher I-strain in $TIPSNTf_2$ would thermodynamically favor the formation of the complex with the smaller carbonyl ligand. We concluded from these studies that R_3SiNTf_2 reagents bearing bulky chiral groups could be effective catalysts for asymmetric Diels–Alder reactions.[6]

The first example of Diels–Alder reactions catalyzed by a chiral electrophilic silylating agent has been recently described.[7] However facial selectivities were still very modest (ee $\leq$ 10%).

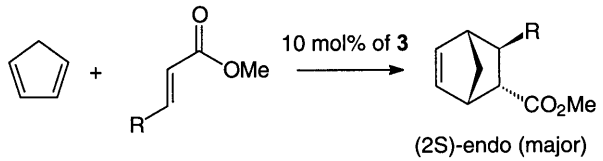
We first decided to examine silylated sulfonimides **3** derived from (–)-myrtenal.[8] The silylcupration of (–)-myrtenal was readily effected by a known procedure to give the *trans* adduct **4**.[9] Its absolute stereochemistry was assigned by an X-ray diffraction analysis.[10] Aldehyde **4** was transformed into **5a–d** by conventional chemistry involving a Wittig reaction/hydrogenation or



Scheme 2. Conditions: (A) CH_3CHPPh_3 then H_2, Pd/C (**5a**, 50%); (B) $LiAlH_4$ then NaH and MeI (**5b**, 83%), $PhCH_2Br$ (**5c**, 90%), or DMAP/PhCOCl (**5d**, 85%); (C) HCl in $CHCl_3$, then $AgNTf_2$ in situ

reduction/etherification, esterification sequence (Scheme 2). The direct protodesilylation of phenylsilanes **5** by $HNTf_2$ led to decomposition product. Treatment of **5** with HCl in $CHCl_3$ gave the corresponding silyl chloride which was readily transformed into **3** by in situ treatment with $AgNTf_2$.[11,2]

Following our expectation, all silylating agents **3a–d** were efficient catalysts for the reaction of cyclopentadiene with methyl acrylate and methyl *trans*-crotonate (Scheme 3, Table 1). Absolute configuration of the cycloadducts were assigned by comparison of their optical rotations with literature data.[12]



Scheme 3.

Table 1
Cycloaddition of cyclopentadiene to methyl acrylate and methyl *trans*-crotonate in the presence of **3a–d**

Entry	Catalyst	R	Conditions	*endo*:*exo*[b]	Yield[c] (%)	ee *endo*[b] (%)
1	3a	H	Toluene, −78°C, 1.5 h	99:1	83	7 (2*S*)
2	3b	H	Toluene, −45°C, 1.5 h[a]	99:1	98	43 (2*S*)
3	**3b**	**H**	**Toluene, −78°C, 1.5 h**	**99:1**	**83**	**54 (2*S*)**
4	**3b**	**H**	**Toluene, −100°C, 1.5 h[a]**	**99:1**	**94**	**54 (2*S*)**
5	3b	Me	Toluene[d], −78°C, 8 h[a]	–	NR	–
6	3b	Me	Toluene, −45°C, 8 h[a]	97:3	93	24 (2*S*)
7	3c	H	Toluene, −78°C, 1.5 h	99:1	79	26 (2*S*)
8	3d	H	Toluene, −78°C, 1.5 h	99:1	80	13 (2*S*)

[a] Reactions were run in the presence of 10 mol% of 2,6-bis(*t*-butyl)-4-methylpyridine.
[b] ee and *endo*:*exo* ratio obtained on a chirasil DEX-CB GC column.
[c] Yield of isolated compound.
[d] Ether, propiononitrile and CH_2Cl_2 were also tested without success.

Catalyst **3a** (entry 1) bearing an alkyl chain gave an adduct with low ee. The introduction of an oxygen atom, which presumably stabilizes the electrophilic center of **3b**, significantly increased the facial selectivity (entries 2 to 6). At −78°C, the ee was 54%, *the highest ee ever reported for an asymmetric silicon Lewis acid catalyzed reaction*. Lowering the temperature to −100°C (entry 4) did not improve the ee. The cycloaddition with methyl crotonate required a higher temperature (−45°C) and enantioselectivities were lower (entries 5 and 6). Attempts were made to change the position or the basicity of the oxygen in the R substituent. Unfortunately, both **3c** and **3d** gave lower enantioselectivities than **3b**.

In summary, we have shown that the association of a bulky leaving group (NTf_2) with a silicon atom bearing large alkyl groups gives rise to efficient Lewis acid catalysts for the Diels–Alder reaction. Also we have prepared the first chiral silicon Lewis acid which lead to significant facial selectivities in Diels–Alder reactions. We believe that these results pave the way for the design and development of tolerant asymmetric Lewis acids catalysts leading to high enantioselectivities.

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References

1. (a) Ghosez, L. In *Stereocontrolled Organic Synthesis*; Trost, B., Ed.; Blackwell Scientific: Oxford, 1994; p. 193. (b) Mbiya, K. *Dissertation*; Université catholique de Louvain: Belgium, 1994.
2. Mathieu, B.; Ghosez, L. *Tetrahedron Lett*. **1997**, *38*, 5497.
3. Jonas, S.; Simchen, G. *J. Prakt. Chem*. **1998**, *340*, 506.
4. Childs, R. F.; Mulholland, D. L.; Nixon, A. *Can. J. Chem*. **1982**, 801; See also: Laszlo, P.; Teston, M. *J. Am. Chem. Soc*. **1990**, *112*, 8750.
5. The occurrence of silylium ions as intermediate is still a matter of controversy. For leading references, see: (a) Reed, C. A. *Acc. Chem. Res*. **1998**, *31*, 325. (b) Ottson, C.-H.; Kraka, E.; Cremer, D. In *Theoretical and Computational Chemistry (Pauling's Legacy)*; Maksic, Z. B.; Orville-Thomas, W. J., Eds.; Elsevier: Amsterdam, 1999; Vol. 6, pp. 231–301. (c) Lambert, J. B.; Kania, L.; Zhang, S. *Chem. Rev*. **1995**, 1191–1201. (d) Maerker, C.; Jürgen, K.; Schleyer, P. R. In *Organosilicon Chemistry II: From Molecules to Materials*; Auner, N.; Weis, J., Eds.; VCH: Weinheim, 1996; pp. 329–359.
6. Chiral silicon compounds were reviewed by: Chan, T. H.; Wang, D. *Chem. Rev*. **1992**, *92*, 995.
7. Johannsen, M.; Jorgensen, K. A.; Helmchen, G. A. *J. Am. Chem. Soc*. **1998**, *120*, 7637; See also: Olah, G. A.; Rasul, G.; Surya Prakash, G. K. *J. Am. Chem. Soc*. **1999**, *121*, 9615.
8. Organoboranes derived from pinene have found widespread use in asymmetric synthesis: Pelter, A.; Smith, K.; Brown, H. C. In *Borane Reagents*; Best Synthetic Methods Series; Katritzky, A. R.; Meth-Cohn, O.; Rees, C. W., Eds.; Academic: London, 1988.
9. Coppi, L.; Ricci, M.; Taddei, M. *Tetrahedron Lett*. **1987**, *28*, 965. In this paper, the authors assigned the *cis*-configuration to their adduct. Extensive ^{1}H and ^{13}C NMR studies (a coupling constant of 7–9 Hz is representative of a *trans*-configuration between the two substituents) unambiguously showed that **4** had the *trans* configuration.
10. X-ray diffraction of the tosylated alcohol derived from **4**: Tinant, B.; Declercq, J.-P., Mathieu, B.; Ghosez, L. *Z. Kristallogr. NCS* **2000**, *215*, 175.
11. Vij, A.; Zheng, Y. Y.; Kirshmeier, R. L.; Shreeve, J. *Inorg. Chem*. **1994**, *33*, 3281.
12. Cycloadduct with methyl acrylate: Berson, J. A.; Walia, J. S.; Remanik, A.; Suzuki, S.; Reynolds-Warnhoff, P.; Willner, D. *J. Am. Chem. Soc*. **1961**, *83*, 3986. Cycloadduct with methyl crotonate: Berson, J. A.; Hammons, J. H.; McRowe, A. W.; Bergman, R. G.; Remanik, A. J.; Houston, D. *J. Am. Chem. Soc*. **1967**, *89*, 2590.