

This article was downloaded by:

On: 27 January 2011

Access details: *Access Details: Free Access*

Publisher *Taylor & Francis*

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Phosphorus, Sulfur, and Silicon and the Related Elements

Publication details, including instructions for authors and subscription information:

<http://www.informaworld.com/smpp/title~content=t713618290>

Silica Triflate as a New, Efficient, and Reusable Reagent for the Chemoselective Silylation of Alcohols and Phenols and Deprotection of Silyl Ethers

F. Shirini^a; K. Marjani^b; H. Taherpour Nahzomi^{ab}; M. A. Zolfigol^c

^a Department of Chemistry, College of Science, The University of Guilan, Rasht, Iran ^b Faculty of Chemistry, Teacher Training University, Tehran, Iran ^c Department of Chemistry, College of Science, Bu-Ali Sina University, Hamadan, Iran

To cite this Article Shirini, F. , Marjani, K. , Nahzomi, H. Taherpour and Zolfigol, M. A.(2008) 'Silica Triflate as a New, Efficient, and Reusable Reagent for the Chemoselective Silylation of Alcohols and Phenols and Deprotection of Silyl Ethers', *Phosphorus, Sulfur, and Silicon and the Related Elements*, 183: 1, 168 — 177

To link to this Article: DOI: 10.1080/10426500701567046

URL: <http://dx.doi.org/10.1080/10426500701567046>

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: <http://www.informaworld.com/terms-and-conditions-of-access.pdf>

This article may be used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan or sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

Silica Triflate as a New, Efficient, and Reusable Reagent for the Chemoselective Silylation of Alcohols and Phenols and Deprotection of Silyl Ethers

F. Shirini,¹ K. Marjani,² H. Taherpour Nahzomi,³
and M. A. Zolfigol⁴

¹Department of Chemistry, College of Science, The University of Guilan, Rasht, Iran

²Faculty of Chemistry, Teacher Training University, Tehran, Iran

³Department of Chemistry, College of Science, The University of Guilan, Rasht, Iran, and Faculty of Chemistry, Teacher Training University, Tehran, Iran

⁴Department of Chemistry, College of Science, Bu-Ali Sina University, Hamadan, Iran

Silica triflate was easily prepared via reaction of silica gel and trifluoromethane sulfonyl chloride at room temperature. This compound can be employed as an efficient and reusable reagent for the chemoselective silylation of alcohols and phenols in solution and under solvent-free conditions. This reagent also effectively catalyzed the deprotection of silyl ethers in refluxing methanol.

Keywords Alcohols; phenols; silica gel; silica triflate; trimethylsilylation

INTRODUCTION

The selective introduction and removal of protecting groups is of great significance in the synthesis of complex organic molecules. The hydroxy group of alcohols and phenols is one of the most versatile functional groups, and its controlled manipulation is of practical value in organic synthesis. The protection of this functionality by conversion

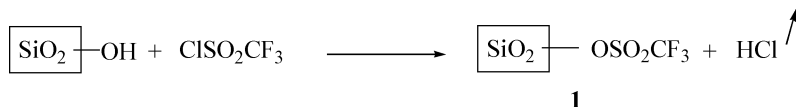
Received October 2, 2006; accepted July 5, 2007.

Partial support of this work by the Guilan and Teacher Training Universities Research Councils are acknowledged. F. Shirini is thankful to Guilan Science and Technology Park (GSTP) for its continuous support. F. Shirini is also indebted to Dr. M. Mottaghtalab for his sincerely assistance.

Address correspondence to F. Shirini, Department of Chemistry, College of Science, The University of Guilan, Rasht 41335, Iran. E-mail: shirini@guilan.ac.ir

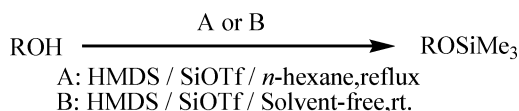
to the corresponding trimethylsilyl ethers is a common practice. Several reagents and methods are available for this purpose,^{1–5} one of them, hexamethyldisilazane (HMDS), a cheap and commercially available reagent,^{6,7} has attracted the attention of organic chemists. Because of the low silylating power of HMDS, a variety of catalysts have been reported for the activation of this reagent.^{8–12} Although the activity of HMDS has been increased drastically using these catalysts, usually low selectivity, forceful conditions and long reaction times have been observed in many of these reports.

In recent years, the interest of our research group was focused on the development of applications of silica gel and its new derivatives in organic chemistry. In the course of our studies we have reported that these reagents can be used efficiently in many organic reactions.^[13–17] In continuation of these studies we have found that trifluoromethane sulfonyl chloride reacts with silica gel to give silica triflate (SiOTf) (**1**) as a white, stable powder (Scheme 1).



SCHEME 1

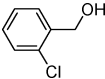
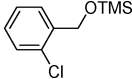
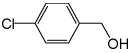
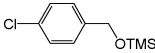
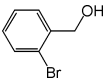
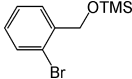
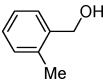
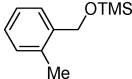
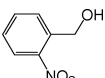
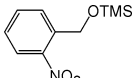
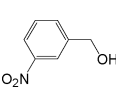
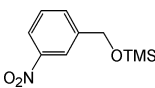
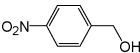
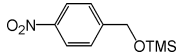
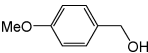
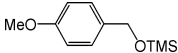
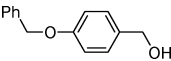
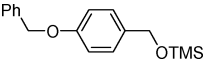


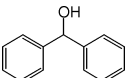
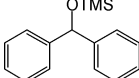
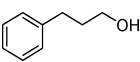
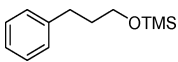
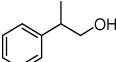
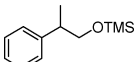
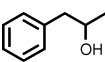
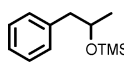
We anticipated, that SiOTf would be more efficient for running reactions under mild conditions, as compared to most of the reported triflates. Therefore, we were interested in using SiOTf for the promotion of trimethylsilylation of alcohols and phenols with hexamethyldisilazane in solution and under solvent-free conditions (Scheme 2).



SCHEME 2

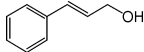
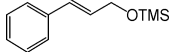
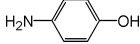
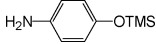
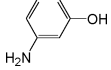
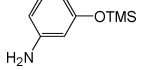
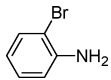
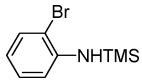
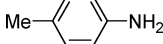
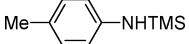
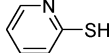
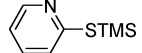
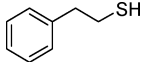
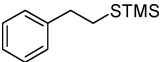
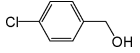
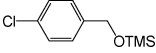
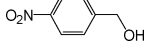
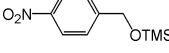


Different types of alcohols were subjected to trimethylsilylation using this method in refluxing *n*-hexane and under completely heterogeneous reaction conditions (Table I). Trimethylsilylation of benzylic alcohols including derivatives with acid sensitive and electron-donating or -withdrawing groups proceeded efficiently with high isolated yields (Table I). Primary and secondary aliphatic alcohols were successfully converted to the corresponding silyl ethers in almost quantitative yields. Cinnamyl alcohol was converted to the corresponding silyl ether in high yields; the carbon-carbon double bond remained intact during

TABLE I Trimethylsilylation of Hydroxy Groups Catalyzed by Silica Triflate ^a

Substrate	Product	Silylation in <i>n</i> -hexane		Solvent-free silylation	
		Time (min)	Yield (%) ^b	Time (min)	Yield (%) ^b
		8	85	2	90
		6	82	2	85
		4	90	2	92
		15	90	3	95
		6	85	2	90
		5	85	2	92
		5	90	2	90
		7	85	2	95
		5	90	2	87
		12	85	3	90
		8	80	2	85
		8	85	2	90
		10	90	3	95
		12	85	41	90

(Continued on next page)

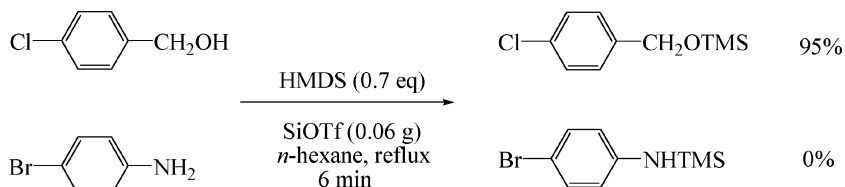
TABLE I Trimethylsilylation of Hydroxy Groups Catalyzed by Silica Triflate ^a (Continued)

Substrate	Product	Silylation in <i>n</i> -hexane		Solvent-free silylation	
		Time (min)	Yield (%) ^b	Time (min)	Yield (%) ^b
		12	90	3	85
		8	90	2	95
		8	85	2	90
(Me) ₃ COH	(Me) ₃ COTMS	30	0 ^c	30	0 ^c
		30	0 ^c	30	0 ^c
		30	0 ^c	30	0 ^c
		30	0 ^c	30	0 ^c
		50	0 ^c	0	0 ^c
		15	0 ^{c,d}	—	—
		15	0 ^{c,e}	—	—
		15	0 ^{c,f}	—	—

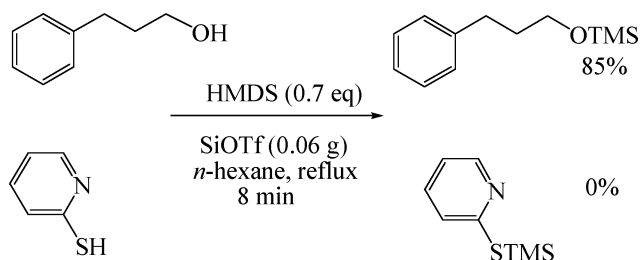
^aProducts were characterized by comparison of their physical constants with those of authentic samples as well as by IR and ¹H NMR spectroscopy; ^bisolated yields; ^cthe starting material was recovered intact; ^dreaction was performed in the presence of silica gel; ^ereaction was performed in the presence of trifluoromethanesulfonyl chloride; and ^freaction was performed in the presence of a mixture of trifluoromethanesulfonyl chloride and silica gel.

the course of the reaction. Phenols also easily undergo silylation using this method and the corresponding silyl ethers were isolated in good to high yields (Table I). As shown in Table I, tertiary alcohols, amines, and thiols are resistant to this reagent and do not react. Thus, this method-

ology shows selectivity and is suitable for the selective trimethylsilylation of benzylic, primary, and secondary aliphatic alcohols and phenols in the presence of amines, thiols, and tertiary alcohols. This is exemplified by the competitive reactions between 4-chlorobenzyl alcohol and 4-bromoaniline and between 3-phenyl-1-propanol and pyridine-2-thiol (Schemes 3 and 4).



SCHEME 3



SCHEME 4

In order to compare these results with those obtained under solvent-free conditions, we studied the silylation reactions in the absence of a solvent. As shown in Table I, there are appreciable differences between the results obtained in solution and those under solvent-free conditions. Omitting the solvent, in addition to a simple work-up procedure, the reaction time was reduced.

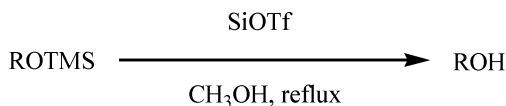
In order to show the efficiency of the present method, Table II compares some of our results with some of those reported in the literature.^{18,19} Deprotection of trimethylsilyl ethers to their parent hydroxyl compounds under mild conditions is a useful achievement in organic synthesis, and a wide variety of methods and catalysts have been already reported for this transformation.^{20–25} However, some of the reported methods suffer from one or more disadvantages, such as the need to use acidic or basic reagents, long reaction times, low yields of the products, high cost or toxicity of the reagents, and a tedious work-up. Therefore, the introduction of a milder, more selective and

TABLE II Comparison of Some of the Results Obtained by the Silylation of Alcohols with HMDS in the presence of Silica Triflate (1), with those obtaining using LiClO_4 (2),¹⁸ and silica chloride (3)¹⁹

Substrate	Time (min)/Yield (%)		
	1	2	3
4- $\text{ClC}_6\text{H}_4\text{CH}_2\text{OH}$	2/85	1.8/67	30/92
4- $\text{MeOC}_6\text{H}_4\text{CH}_2\text{OH}$	2/95	1.3/69	30/80
PhCH=CHCH ₂ OH	3/85	1/70	18/70

heterogeneous reagent for such functional group transformations is of practical importance and still in demand.

Our studies revealed that silica triflate can also be used as an efficient reagent for the conversion of trimethylsilyl ethers to the corresponding alcohols in refluxing methanol. All reactions were performed under completely heterogeneous reaction conditions and resulted in good to high yields (Scheme 5, Table III).



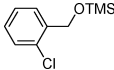

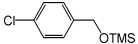
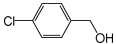
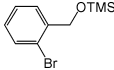

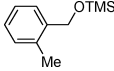

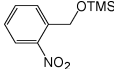

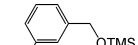
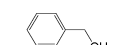
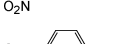

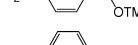
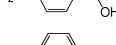
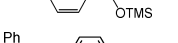
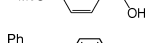
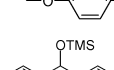
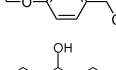
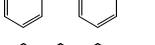
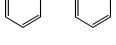
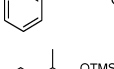
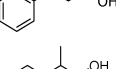
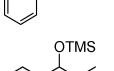
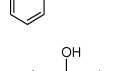
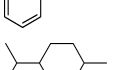
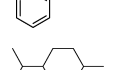
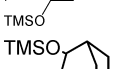
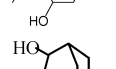
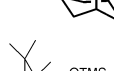
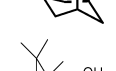
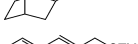
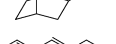
SCHEME 5

We have found that silica triflate is a reusable catalyst and even after five runs for the silylation of alcohols and phenols and for the deprotection of trimethylsilyl ethers, the catalytic activity of the reagent was almost the same as compared to that of the freshly used catalyst. The same IR spectra of the reagent were obtained before and after its use in the reactions, which demonstrates the stability of its composition.

It should be noted that the silylation and desilylation reactions did not proceed using silica gel and trifluoromethanesulfonyl chloride alone or by the separate addition of these reagents to the reaction mixture (Table I).

In conclusion, in this article we have reported the preparation of silica triflate as a new and stable silica-based reagent, and its application in efficient trimethylsilylation of alcohols and phenols, as well as in the deprotection of silyl ethers. Short reaction times, reusability of the reagent, high yields of the products, easy work-up, and chemoselectivity are important advantages of this method, which make this procedure a useful and attractive addition to the currently available methods.

TABLE III Deprotection of Trimethylsilyl Ethers^a

Substrate	Product	Time (min)	Yield (%) ^b
		4	95
		4	90
		3	92
		5	90
		5	95
		4	90
		4	95
		3	90
		3	95
		8	90
		2	85
		4	90
		4	95
		4	90
		4	85
		4	90
		3	95

^aProducts were characterized by comparison of their physical constants with those of authentic samples as well as by IR and ¹H NMR spectroscopy; and ^bisolated yields.

EXPERIMENTAL

Chemicals were purchased from Fluka, Merck, and Aldrich. Products were characterized by comparison of their physical constants with those of authentic samples, as well as by IR and ^1H NMR spectroscopy.

Preparation of Silica Triflate

A 500 mL suction flask, charged with 18.0 g silica gel (type 60, 15–40 μm), was equipped with a constant pressure dropping funnel containing trifluoromethane sulfonyl chloride (8.4 g, 0.05 mol) and a gas inlet tube for conducting HCl gas over an adsorbing solution i.e. water. Trifluoromethane sulfonyl chloride was added dropwise over a period of 30 min and the reaction mixture was stirred slowly at room temperature for 30 min. The mixture was then heated to 60°C for 1 h while stirring to remove all HCl. The resulting product was washed with 50 mL of dry CH_2Cl_2 and dried under vacuum. Silica triflate was obtained as a white solid (20.38–20.6 g), which was stored in a capped bottle. In order to determine the amount of the active triflate in the reagent, the produced HCl from the above reaction was titrated with 0.1 M NaOH. The result from several runs showed the formation of 0.018–0.020 mol of HCl; therefore, the amount of active triflate content was determined to be 1 mmol per 1.04–1.08 g silica triflate; IR (KBr): 1255, 1230, 1130, 1010, 955, 820, 650, 530, 500 cm^{-1} .

Trimethylsilylation in *n*-Hexane

A mixture of the substrate (1 mmol), HMDS (0.11 g, 0.7 mmol) and silica triflate (0.06 g) in *n*-hexane (4 mL) was stirred at reflux conditions. The progress of the reaction was monitored by GC or TLC. After completion of the reaction the mixture was filtered through a silica gel pad. The filter cake was washed with *n*-hexane (5 mL). From the combined filtrates the solvent was evaporated to afford the silylated compound in high purity. Further purification proceeded by bulb to bulb distillation under reduced pressure, which afforded the desired silyl ether in good to high yields.

Trimethylsilylation under Solvent-Free Conditions

A mixture of the substrate (1 mmol), HMDS (0.11 g, 0.7 mmol) and silica triflate (0.06 g) was shaken at room temperature for the specified time. The progress of the reaction was monitored by GC or TLC. After completion of the reaction the mixture was triturated with *n*-hexane

(10 mL) and then filtered. Evaporation of the solvent under reduced pressure gave almost pure product. Further purification proceeded by bulb to bulb distillation under reduced pressure, vacuum distillation or recrystallization to afford pure silyl ether.

Deprotection of Trimethylsilyl Ethers

A mixture of the substrate (1 mmol) and silica triflate (0.06 g) in methanol (4 mL) was stirred under reflux conditions. The progress of the reaction was monitored by GC or TLC. After completion of the reaction the mixture was filtered and the solid residue was washed with methanol (3 mL). Evaporation of the solvent followed by column chromatography on silica gel ($\text{CCl}_4/\text{Et}_2\text{O}$: 4/1) gave the corresponding alcohols in good to high yields.

REFERENCES

- [1] T. W. Green and P. G. M. Wuts, *Protective Groups in Organic Synthesis* (Wiley, New York, 1999), 3rd ed.
- [2] G. A. Olah, B. G. B. Gupta, S. C. Narang, and R. Malhotra, *J. Org. Chem.*, **44**, 4272 (1979).
- [3] I. Nishiguchi, Y. Kita, M. Watanabe, Y. Ishino, T. Ohno, and H. Maekawa, *Synlett*, 1025 (2000).
- [4] J. M. Aizpurua and C. Palmo, *Bull. Soc. Chim. Fr.*, 265 (1982).
- [5] Y. Tanabe, M. Murakami, K. Kitachi, and Y. Yoshida, *Tetrahedron Lett.*, **45**, 8409a. (1994).
- [6] S. Tarkelson and C. Ainsworth, *Synthesis*, 722 (1976).
- [7] J. Cossy and P. Pale, *Tetrahedron Lett.*, **28**, 6039 (1987).
- [8] P. Gautret, S. El-Ghammarti, A. Legrand, D. Couturier, and B. Rigo, *Synth. Commun.*, **26**, 707 (1996).
- [9] A. G. Goldschmidt, *German Patent* 2758884 (1979).
- [10] H. Firouzabadi, A. R. Sardarian, Z. Khayat, B. Karimi, and S. Tangestaninejad, *Synth. Commun.*, **27**, 2709 (1997).
- [11] M. Curini, F. Epifano, M. C. Marcotullio, O. Rosati, and U. Constantino, *Synth. Commun.*, **29**, 541 (1999).
- [12] J. Feixas, F. Camps, and A. Guerrero, *Bioorg. Med. Chem. Lett.*, **2**, 467 (1992).
- [13] F. Shirini, M. A. Zolfigol, and K. Mohammadi, *Bull. Korean Chem. Soc.*, **24**, 519 (2003).
- [14] F. Shirini, M. A. Zolfigol, and M. Khaleghi, *Phosphorus, Sulfur, and Silicon*, **178**, 1999 (2003).
- [15] M. A. Zolfigol, F. Shirini, A. Ghorbani Choghamarani, and I. Mohammadpoor-Baltork, *Green Chem.*, **4**, 562 (2002).
- [16] M. A. Zolfigol, F. Shirini, I. Mohammadpoor-Baltork, A. Ghorbani Choghamarani, M. Hajjami, and A. M. Sedaghat, *Mendeleev Commun.*, 133 (2005).
- [17] M. A. Zolfigol, T. Madrakian, E. Ghaemi, A. Afkhami, S. Azizian, and S. Afshar, *Green Chem.*, **4**, 611 (2002).
- [18] B. P. Bandgar and S. P. Kasture, *Monatsh. Chem.*, **132**, 1101 (2001).

- [19] F. Shirini, M. A. Zolfigol, and K. Mohammadi, *Phosphorus, Sulfur, and Silicon*, **178**, 1567 (2003).
- [20] Z.-H. Zhang, T.-S. Li, F. Yang, and C.-G. Fu, *Synth. Commun.*, **28**, 3105 (1998).
- [21] J. Feixas, A. Capdevila, F. Camps, and A. Guerrero, *J. Chem. Soc., Chem. Commun.*, 1451 (1992).
- [22] A. D. Cort, *Synth. Commun.*, **20**, 757 (1990).
- [23] N. S. Wilson and B. A. Keay, *Tetrahedron Lett.*, **38**, 187 (1997).
- [24] A.S.-Y. Lee, H.-C. Yeh, and J.-J. Shie, *Tetrahedron Lett.*, **39**, 5349 (1998).
- [25] H. Firouzabadi and F. Shirini, *Synth. Commun.*, **26**, 423 (1996).