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Preparation of Silyl Enol Ethers Using (Bistrimethylsilyl)acetamide in Ionic Liquids

Michael Smietana and Charles Mioskowski*

Laboratoire de Synthèse Bio-organique, CNRS and Université Louis Pasteur,
Faculté de Pharmacie, 74 Route du Rhin, 67401 Illkirch, France

mioskow@aspirine.u-strasbg.fr

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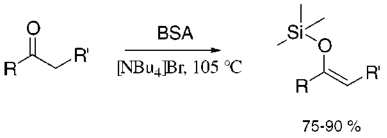
ABSTRACT



Ionic liquids have been used for the preparation of silyl enol ethers from aldehydes and ketones with (bistrimethylsilyl)acetamide (BSA) in good yields.

Synthetic utility and importance of silyl enol ethers has been well established, and their preparations have been extensively studied[1] and reviewed.[2] The most common methods use silyl chlorides or silyl triflates/base combinations and need careful attention during workup of the reaction and isolation of the enol ether.

Silylations with silazane-type reagents such as (bistrimethylsilyl)acetamide (BSA) are generally mild and nearly neutral. The use of a co-base to capture the acid proton is not needed and is operationally more convenient due to the ease of preparation and handling. However, the reactivity of these silicon-based reagents often remains low and unsatisfactory. To our knowledge, the only example of the silylation of enolizable aldehydes and ketones with BSA uses hexamethylphosphoramide (HMPA) as the solvent in the presence of small quantities of sodium metal.[3,4] According to the authors, this reaction does not work with any other solvent and the high toxicity of HMPA requires special precautions.

Because of their solvent properties, ionic liquids are attracting increasing attention.[5] They afford significant environmental benefits and can contribute to green chemistry. They are low melting, nonvolatile, and exhibit good physicochemical properties and can be recovered by careful washing in ether or pentane.

Recently ionic liquids have been reported as alternative solvents for polymerization,[6] hydrogenation,[7] regioselective alkylation,[8] Friedel−Crafts reactions,[9] dimerization of alkenes,[10] Diels−Alder reactions,[11] and cross-coupling reactions.[12] In this Letter we report an efficient, fairly concen-

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(1) For recent papers about the formation of enoxysilanes, see: (a) Hydrio, J.; Van de Weghe, P.; Collin, J. *Synthesis* **1997**, 68. (b) Ishino, Y.; Kita, Y.; Maekawa, H.; Ohno, T.; Yamasaki, Y.; Miyata, T.; Nishiguchi, I. *Tetrahedron Lett*. **1999**, *40*, 1349.

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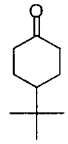
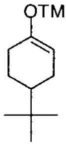
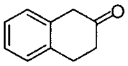
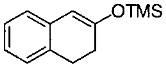
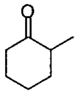
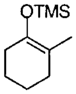
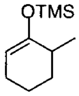
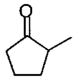
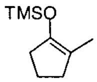
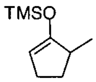
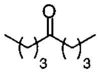
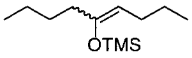
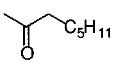
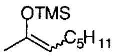
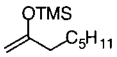
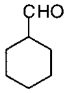
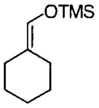
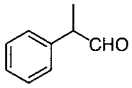
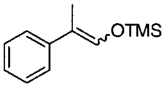
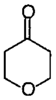
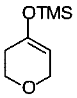
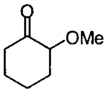
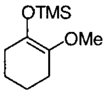
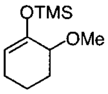
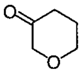
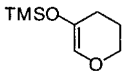
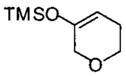
Table 1. Synthesis of Enoxysilanes from Aldehydes and Ketones with BSA

Entry	Substrate	Product[a]	Yield[b] (%)
1			93
2			80
3		 90  10	90
4		 90  10	85
5			85
6		 70  30	87
7			83
8			75
9			84
10		 40  60	90
11		 20  80	80

[a] Selectivity was determined by ^{1}H NMR. [b] Isolated yield (%).

trated, and environmentally friendly preparation of enoxysilanes from aldehydes and ketones by treatment with BSA in different ionic liquids.

Typically, the enoxysilanes were obtained in tetrabutylammonium bromide at 105 °C and isolated directly by stripping the product from the crude mixture.[13] The results are outlined in Table 1. The reactions are completed in 4 h and produce the enoxysilanes in high yields. In the case of carbonyl compounds that can lead to two regioisomeres, the thermodynamic one is formed preferentially (entries 2, 3, 4, and 6). It is noteworthy that the product distribution changes with α-heteroatom-substitued ketones (entries 10 and 11). Moreover, when chlorotrimethylsilane is used as reagent under the same conditions, only the crotonization products are formed. With other silazane-type reagents, such as bis(trimethylsilyl urea) or trimethylsilyl imidazole, no reaction is observed.

To examine the behavior of other molten salts, we have considered the reactivity of cyclohexanone in the presence of BSA. The results are reported in Table 2. The best yields were obtained with phosphonium and ammonium salts (entries 1−4). In the case of phosphonium salts, bromide and chloride led to similar yields (entries 1 and 2). On the other hand, the ammonium salts gave different results. Whereas the bromide seems to be a very good medium (entry 3), the yield decreased significantly with the chloride (entry 4). Longer reaction times and amounts of BSA were required to increase the yield. With *N*-butylpyridinium bromide[14] ([BuPy][Br]), very small amounts of enoxysilane were formed but no starting ketone was recovered (entry 5). We also examined the behavior of room-temperature ionic liquids at various temperatures. Surprisingly, the generation of silyl enol ethers was not observed with 1-butyl-3-methylimidazolium chloride ([bmim][Cl]) nor with 1-butyl-3-methylimidazolium hexafluorophosphate ([bmim][PF$_6$]),[15] even at 90 °C (entries 6 and 7). In both cases, the starting ketone was entirely recovered.

Table 2. Synthesis of 1-(Trimethylsilyloxy)cyclohexene in Different Molten Salts

entry	solvent	temp (°C)	yield (%)[a]
1	[PBu$_4$]Br	105	87
2	[PBu$_4$]Cl	85	80
3	[NBu$_4$]Br	105	90
4	[NBu$_4$]Cl	85	45
5	[BuPy]Br	90	15
6	[bmim]Cl	90	0
7	[bmim][PF$_6$]	90	0

[a] Isolated yields.

In conclusion, these results demonstrate the potential of molten salts, e.g., tetrabutylammonium bromide, for the generation of enoxysilanes with BSA in neutral conditions without any base addition. The nature of the salt and

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(13) **Typical procedure for the preparation of enoxysilanes:** A few degrees above the melting temperature of tetrabutylammonium bromide (5 mmol; ca. 105 °C), the carbonyl compound was added (2 mmol), followed by addition of BSA (2.4 mmol). The mixture was stirred for 4 h at this temperature and directly distilled under reduced pressure whithout any workup to give pure silyl enol ether.

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especially the nature of the cation proved to be important parameters. These new reaction conditions open an important alternative to the use of toxic solvents. Studies are underway to develop other significant applications to reduce toxic waste by using ionic liquids.

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Supporting Information Available: Spectroscopy data and analytical data of compounds prepared in Table 1. This material is available free of charge via the Internet at http//pubs.acs.org.

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