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Synthesis of vinyl sulfides under base-free conditions using selenium ionic liquid

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ABSTRACT

A very simple procedure is described for the efficient synthesis of vinyl sulfides by hydrothiolation of terminal alkynes using 1-*n*-butyl-3-methylimidazolium methylselenite, [bmim][SeO₂(OCH₃)]. The reaction proceeds cleanly under mild, base-free conditions and was performed with aromatic and aliphatic thiols. © 2012 Elsevier Ltd. All rights reserved.

Besides being very useful tools in organic reactions and acting as key intermediates in organic synthesis,¹ vinyl sulfides are present in naturally occurring compounds, such as griseoviridin and benzylthiocredillidone, which present important biological activities.^{2,3} Between the several methods described for the preparation of vinyl sulfides, the most common and atom-economic protocols involve the addition of thiol, or the respective anions, to terminal or internal alkynes. These methods are of two major groups: those involving transition-metals as catalyst⁴ and the base-promoted ones.⁵ More recently, some improvements on selective preparation of vinyl sulfides have been described.^{6–12} These comprise the use of catalytic phenylselenenyl bromide,⁶ nickel,⁷ gold,⁸ or native silica nanoparticle⁹ under solvent-free conditions, β-cyclodextrin in the presence of water and acetone,¹⁰ KF/Al₂O₃ under solvent-free¹¹ or under catalyst-free conditions.¹²

The use of ionic liquids (ILs) as catalyst has attracted great attention in the last years. Because product isolation or catalyst recycling is very easy in ILs and, in some cases, rate accelerations and/or selectivity improvements are also observed, they are regarded as environmentally friendly, green solvents.¹³ In this context, recently we have reported the use of the new cationic selenium-based acidic ionic liquid, phenyl butyl ethyl selenonium tetrafluoroborate, [pbeSe][BF₄], as an efficient catalyst in several acid-catalyzed reactions.¹⁴ Besides, the application of the ionic liquid containing anionic selenium-based [bmim][SeO₂(OCH₃)] in the oxidative carbonylation of aniline¹⁵ and in the base-free oxidation of thiols to disulfides were recently described.¹⁶ To the best of our knowledge, the methods to access vinyl sulfides from thiols

* Corresponding author. Tel./fax: +55 53 32757533. E-mail address: lenardao@ufpel.edu.br (E.J. Lenardão). and alkynes under base-free conditions are limited.⁶⁻¹² In this sense, and due to our interest in new applications for selenium-based ionic liquids, we decided to investigate the use of [bmim] [SeO₂(OCH₃)] in the hydrothiolation of terminal alkynes to prepare vinyl sulfides (Scheme 1).



Scheme 1. General scheme of the reaction.



Figure 1. Plot of conversion versus time for the reaction between propargyl alcohol **1a** and benzenethiol **2a**; determined by GC.





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Entry	Alkyne 1	Thiol 2	Product 3 + 4	Time	Ratio ^a 3 Z: 3 E: 4	Yield ^b (%)
1	1a OH	C ₆ H ₅ SH 2a	C_6H_5S C_6H_5	16	48:2:50	80
2	1a	C ₆ H₅CH₂SH 2b	$C_6H_5CH_2S$ $H_2C_6H_5$ $C_6H_5CH_2S$ $H_2C_6H_5$	16	53:3:44	63
3	1a	o-ClC ₆ H₄SH 2c	$O-CIC_6H_4S^{2}$ OH + CC_6H_4-O-CI 3c 4c OH	10	60:8:32	78
4	1a	m-ClC ₆ H₄SH 2d	m-CIC ₆ H ₄ CH ₂ S $3d$ $4d$ $SCH_2C_6H_4$ - m -CI	9	56:13:31	62
5	1a	p-ClC ₆ H₄SH 2e	p-Cl-C ₆ H ₄ CH ₂ S ⁵ OH + SCH ₂ C ₆ H ₄ - p -Cl 3e 4e OH	15	31:12:57	70
6	1a	o-CH₃C ₆ H₄SH 2f	$O-CH_3C_6H_4S^{3}-OH + $ $3f$ $SC_6H_4-O-CH_3$ $SC_6H_4-O-CH_3$	12	37:11:51	51
7	1a	m-CH₃C ₆ H₄SH 2g	m -CH ₃ C ₆ H ₄ s ² -OH + SC_6H_4 - m -CH ₃ 3g + 4g - OH	13	31:12:57	63
8	1a	p-CH₃C ₆ H₄SH 2h	$\rho\text{-CH}_{3}C_{6}H_{4}S^{3} OH + \underbrace{\qquad}_{\mathbf{A}}C_{6}H_{4}-\rho\text{-CH}_{3}$ 3h 4h OH	12	25:46:29	75
9	1a	CH ₃ (CH ₂) ₁₁ SH 2i	$C_{12}H_{25}S^{5} - OH^{+} = SC_{12}H_{25}$ 3i 4i - OH	8	44:2:54	45
10	≡OH	2a	C_6H_5S GH_5 GH_5 H_5	10	14:29:57	78
11	≡ 1c OH	2a	$C_6H_5S \xrightarrow{5} OH + OH + OH$	17	19:7:74	97
12	Id OH	2a	$C_6H_5S \xrightarrow{S}_{HO}$ + $HO \xrightarrow{SC_6H_5}_{HO}$	23	53:20:27	60
13	1e	2a	$C_{6}H_{5}S^{5}C_{6}H_{13}^{+}$ $= C_{6}H_{13}$	21	80:20:0	30
14	==−C ₆ H ₅ 1f	2a	$C_6H_5S \xrightarrow{s} C_6H_5 + = SC_6H_5$ 3n 4n C_6H_5	2	42:4:53	98
15	1f	2e	$p\text{-CIC}_{6}H_{4}S^{5}C_{6}H_{5}^{+} = \overset{SC_{6}H_{4}-p\text{-CI}}{40}C_{6}H_{5}$	2	61:24:15	93

^a Determined by ¹H NMR of the crude reaction mixture and confirmed after isolation of the mixture of formed isomers.

^b Yields of the mixture of isomers obtained by column chromatography eluting with hexanes (**3m-3o**) or with hexanes/ethyl acetate (98:2, **3a-3l**).

A set of experiments were performed to find the best conditions for the synthesis of vinyl sulfides using thiophenol and propargyl alcohol as model starting materials. Careful analysis revealed that the best yields were obtained when a mixture of alkyne **1a** (1.2 mmol), thiol **2a** (1.0 mmol), and [bmim][SeO₂(OCH₃)] (15.8 mg, 5 mol %) was vigorously stirred at 60 °C under nitrogen atmosphere. Under this condition, a mixture of the respective adducts **3a** and **4a** was obtained in 80% overall yield after 16 h (Table 1, entry 1).

The nitrogen atmosphere was crucial to minimize the formation of disulfide by the oxidation of thiol. In order to obtain an efficient protocol in terms of energy efficiency, we made a study to establish the minimum time associated with a good reaction rate under optimized conditions, the results are summarized in Figure 1. As can be seen in the Figure, the adducts can be detected after 1 h of reaction and the highest yield was observed after 16 h (80%, green line). The diphenyl disulfide observed in the chromatogram (red line) probably was formed during the quenching process just before the injection in the chromatograph, once this procedure was performed in open atmosphere (air presence). We have already described that [bmim][SeO₂(OCH₃)] is a good oxidant agent in the presence of air.¹⁶ This assumption was confirmed when diphenyl disulfide was used instead of benzenethiol; no product was verified even after 24 h of stirring at 60 °C.

With this optimized condition in hand,¹⁷ a detailed study was performed with aliphatic and aromatic thiols and several alkynes, as propargyl alcohols, phenylacetylene, and octyne, showing the generality of the method. The results depicted in Table 1 show that [bmim][SeO₂(OCH₃)] was an excellent catalyst, affording a wide range of vinyl sulfides. Concerning the stereochemistry of products, for all the hydroxylated alkynes 1a-1d, a mixture of Markovnikov and anti-Markovnikov adducts was obtained (Table 1, entries 1-12). Despite the low selectivity, a good yield was achieved in most of the tested examples. An exception was the reaction between octyne 1e with benzenethiol 2a, which afford the respective *anti*-Markovnikov adduct **3n** in 30% yield and a Z/E ratio = 80:20 (entry 13). Under our conditions, phenyl acetylene 1f reacted with 2a to afford a 1:1 mixture of isomers 3n and 4n in excellent yield (Table 1, entry 14). The best selectivity was obtained when p-chlorobenzenethiol 2e was used, in preference to the anti-Markovnikov adduct, (Z)-30 (entry 15).

To speculate if a radical mechanism could be involved, the reaction was also performed in the presence of hydroquinone. Thus, when a mixture of **1a**, **2a**, and the ionic liquid reacted in the presence of hydroquinone (10 mol %), the respective adducts were obtained in same yields and isomeric relation as described above (Table 1, entry 1).

In conclusion, we have described a new application for the selenium-based ionic liquid [bmim][SeO₂(OCH₃)], which was an efficient catalyst for the synthesis of a range of vinyl sulfides via hydrothiolation of alkynes. This is a useful alternative to the existing methodologies, once no strong bases are involved.

Acknowledgments

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References and notes

 For the synthetic utility of vinyl sulfides see, for example: (a) Aucagne, V.; Lorin, C.; Tatibouët, A.; Rollin, P. Tetrahedron Lett. 2005, 46, 4349; (b) Muraoka, N.; Mineno, M.; Itami, K.; Yoshida, J.-I. J. Org. Chem. 2005, 70, 6933; (c) Woodland, C. A.; Crawley, G. C.; Hartley, R. C. Tetrahedron Lett. 2004, 45, 1227; (d) McReynolds, M. D.; Dougherty, J. M.; Hanson, P. R. Chem. Rev. 2004, 104, 2239; (e) Oae, S. Organic Sulfur Chemistry: Structure and Mechanism; CRC Press: Boca Raton, FL, 1991; (f) Cremlyn, R. J. An Introduction to Organosulfur Chemistry; Wiley & Sons: New York, 1996.

- (a) Marcantoni, E.; Massaccesi, M.; Petrini, M. J. Org. Chem. 2000, 65, 4553; (b) Kuligowski, C.; Bezzenine-Lafollée, S.; Chaume, G.; Mahuteau, J.; Barrière, J.-C.; Bacqué, E.; Pancrazi, A.; Ardisson, J. J. Org. Chem. 2002, 67, 4565.
- Lan, H. W.; Cooke, P. A.; Pattenden, G.; Bandaranayake, W. M.; Wickramasinghe, W. A. J. Chem. Soc., Perkin Trans. 1 1999, 847.
- (a) Kondo, T.; Mitsudo, T. Chem. Rev. 2000, 100, 3205; (b) Cao, C.; Fraser, L. R.; Love, J. A. J. Am. Chem. Soc. 2005, 127, 17614; (c) Weiss, C. J.; Wobser, S. D.; Marks, T. J. J. Am. Chem. Soc. 2009, 131, 2062; (d) Ogawa, A.; Ikeda, T.; Kimura, K.; Hirao, T. J. Am. Chem. Soc. 1999, 121, 5108; (e) Malyshev, D. A.; Scott, N. M.; Marion, N.; Stevens, E. D.; Ananikov, V. P.; Beletskaya, I. P.; Nolan, S. P. Organometallics 2006, 25, 4462.
- (a) Waters, M. S.; Cowen, J. A.; McWilliams, J. C.; Maligres, P. E.; Askin, D. *Tetrahedron Lett.* **2000**, *41*, 141; (b) Dabdoub, M. J.; Dabdoub, V. B.; Lenardão, E. J.; Hurtado, G. R.; Barbosa, S. L.; Guerrero, P. G., Jr.; Nazário, C. E. D.; Viana, L. H.; Santana, A. S.; Baroni, A. C. M. *Synlett* **2009**, 986; (c) Wadsworth, D. H.; Detty, M. R. J. Org. Chem. **1980**, *45*, 4611.
- Manarin, F.; Roehrs, J. A.; Prigol, M.; Alves, D.; Nogueira, C. W.; Zeni, G. Tetrahedron Lett. 2007, 48, 4805.
- Ananikov, V. P.; Orlov, N. V.; Beletskaya, I. P. Organometallics 2006, 25, 1970.
 Corma, A.; González-Arellano, C.; Iglesias, M.; Sánchez, F. Appl. Catal., A: Gen. 2010, 375, 49.
- Banerjee, S.; Das, J.; Santra, S. Tetrahedron Lett. 2009, 50, 124.
- Sridhar, R.; Surendra, K.; Krishnaveni, N. S.; Srinivas, B.; Rao, K. R. Synlett 2006, 3495.
- (a) Silva, M. S.; Lara, R. G.; Marczewski, J. M.; Jacob, R. G.; Lenardão, E. J.; Perin, G. Tetrahedron Lett. **2008**, 49, 1927; (b) Lenardão, E. J.; Silva, M. S.; Lara, R. G.; Marczewski, J. M.; Sachini, M.; Jacob, R. G.; Alves, D.; Perin, G. Arkivoc **2011**, 2, 272.
- Schneider, C. C.; Godoi, B.; Prigol, M.; Nogueira, C. W.; Zeni, G. Organometallics 2007, 26, 4252.
- (a) Tadesse, H.; Luque, R. Energy Environ. Sci. 2011, 4, 3913; (b) Welton, T. Chem. Rev. 1999, 99, 2071; (c) Dupont, J.; Souza, R. F.; Suarez, P. A. Z. Chem. Rev. 2002, 102, 3667; (d)Wasserscheid, P., Welton, P., Eds.Jonic Liquids in Synthesis; Wiley-VCH: Weinheim, 2003; (e) Rantwijk, F.; Sheldon, R. A. Chem. Rev. 2007, 107, 2757; (f) Martins, M. A. P.; Frizzo, C. P.; Moreira, D. N.; Zanatta, N.; Bonacorso, H. G. Chem. Rev. 2008, 108, 2015.
- (a) Lenardão, E. J.; Feijó, J. O.; Thurow, S.; Perin, G.; Jacob, R. G.; Silveira, C. C. Tetrahedron Lett. **2009**, 50, 5215; (b) Lenardão, E. J.; Borges, E. L.; Mendes, S. R.; Perin, G.; Jacob, R. G. Tetrahedron Lett. **2008**, 49, 1919; (c) Lenardão, E. J.; Mendes, S. R.; Ferreira, P. C.; Perin, G.; Silveira, C. C.; Jacob, R. G. Tetrahedron Lett. **2006**, 47, 7439.
- For the synthesis of [bmim][SeO₂(OCH₃)] see: Kim, H. S.; Kim, Y. J.; Lee, H.; Park, K. Y.; Lee, C.; Chin, C. S. Angew. Chem., Int. Ed. **2002**, *41*, 4300.
- Thurow, S.; Pereira, V. A.; Martinez, D. M.; Alves, D.; Perin, G.; Jacob, R. G.; Lenardão, E. J. *Tetrahedron Lett.* **2011**, *52*, 640.
- 17. General procedure for the synthesis of vinyl sulfides with [bmim][SeO₂(OCH₃)]: In a Schlenk tube under nitrogen atmosphere and at 60 °C, propargyl alcohol (**1a**; 0.067 g; 1.2 mmol) and benzenethiol (**2a**; 0.110 g; 1 mmol) were added to [bmim][SeO₂(OCH₃)]¹⁵ (0.0158 g, 0.05 mmol). The reaction mixture was allowed to stir at 60 °C for the time indicated in Table 1. The progress of the reaction was monitored by TLC or GC. After the reaction was complete, water (15 mL) was added and the organic phase was extracted with EtOAc (3×5 mL), dried over MgSO₄, and concentrated under vacuum. The residue was purified by column chromatography on silica gel using hexanes/ethyl acetate (90:10) as eluent, yielding a mixture of **3a** and **4a** (0.133 g, 80%). ¹H NMR (400 MHz, CDCl₃)^{11b} δ *Z* isomer: 7.21–7.42 (m, 5H); 6.35 (dt, *J* 9.2 and 1.2, 1H); 5.96 (dt, *J* 9.2 and 6.6, 1H); 4.37 (dd, *J* 6.6 and 1.2, 2H); 1.92 (br s, 1H); *E* isomer: 7.21–7.42 (m, 5H); 6.46 (dt, *J* 15.6 and 1.2, 1H); 5.57 (dt, *J* 15.6 and 6.8, 1H); 4.20 (dd, *J* 6.8 and 1.2, 2H); 1.92 (br s, 1H).