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Article

$NaBH_4$/[bmim]BF_4: a New Reducing System to Access Vinyl Selenides and Tellurides

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Um método simples e geral foi desenvolvido para a síntese de selenetos e teluretos vinílicos a partir de alquinos terminais e dicalcogenetos de diorganoíla usando $NaBH_4$ e [bmim]BF_4 como solvente reciclável. Este método eficiente permite a formação preferencial de calcogenetos vinílicos de configuração *Z* na maioria dos exemplos estudados. Também foi observado que na reação envolvendo fenilacetileno, (*E*)-bis-fenilcalcogenoestirenos foram obtidos com bons rendimentos e alta seletividade. O líquido iônico foi reutilizado três vezes sem perda da eficiência.

A general and simple method for the synthesis of vinyl selenides and tellurides starting from terminal alkynes and diorganyl chalcogenides using $NaBH_4$ and [bmim]BF_4 as a recyclable solvent was developed. This efficient and improved method furnishes the corresponding vinyl chalcogenides preferentially with *Z* configuration. We also observed that when the same protocol was applied to phenyl acetylene, (*E*)-bis-phenylchalcogeno styrenes were obtained in good yields and high selectivity. The ionic liquid was reused up three times without lost of efficiency.

Keywords: ionic liquids, hydrochalcogenation, vinyl chalcogenides

Introduction

Vinyl chalcogenides have been found to be a very useful tool in organic synthesis, since they are very versatile intermediates for the selective construction of isolated or conjugated olefins.[1-10] Besides, organoselenium and organotellurium compounds have attracted increased interest because of their unique biological and pharmacological properties.[11,12] In this way, various methods are mentioned for the preparation of vinyl chalcogenides and the most common protocols involve the addition of organo chalcogenol, or the respective chalcogenolate anions, to terminal or internal alkynes.[1-10,13-20] On the other hand, ionic liquids (ILs) are receiving much attention in organic synthesis, both as recyclable solvents and/or catalysts.[21-32] 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. In despite of the high versatility of vinyl chalcogenides and the green feature of ILs, their use as solvent for hydrochalcogenation reaction of alkynes was scarcely explored.[33] As a continuation of our studies toward the development of new and cleaner methods for the synthesis of organochalcogenides,[33-40] we report herein the full results on the hydrochalcogenation of alkynes using $NaBH_4$ and [bmim]BF_4 as recyclable solvent for the synthesis of vinyl selenides and tellurides (Scheme 1).

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Experimental

General remarks

Proton nuclear magnetic resonance spectra (^{1}H NMR) were obtained at 200 MHz on a Bruker DPX-200 NMR spectrometer. Spectra were recorded in $CDCl_3$ solutions. Chemical shifts are reported in ppm, referenced to the solvent peak of $CDCl_3$ or tetramethylsilane (TMS) as the internal reference. Data are reported as follows: chemical shift (δ), multiplicity, coupling constant *(J)* in Hertz and integrated intensity. Carbon-13 nuclear magnetic resonance spectra (^{13}C NMR) were obtained at 50 MHz on a Bruker DPX-200 NMR spectrometer. Spectra were recorded in $CDCl_3$ solutions. Chemical

shifts are reported in ppm, referenced to the solvent peak of $CDCl_3$. Column chromatography was performed using Merck Silica Gel (230-400 mesh) following the standard methods. Thin layer chromatography (TLC) was performed using Merck Silica Gel GF_{254}, 0.25 mm thickness. For visualization, TLC plates were either placed under ultraviolet light, or stained with iodine vapor, or acidic vanillin. The reactions were monitored by TLC for disappearance of starting material. Reactions were conducted in flame-dried glassware equipped with tightly fitted rubber septa and under a positive atmosphere of dry nitrogen. Reagents were handled using standard syringe techniques.

General procedure for the synthesis of vinyl chalcogenides

To a mixture of alkyne (2.0 mmol) and diphenyl diselenide (0.156 g; 0.5 mmol) in $[bmim]BF_4$ (0.5 mL) under N_2 atmosphere, $NaBH_4$ (0.045 g; 1.2 mmol) was added at room temperature. Then, the temperature was slowly raised to 60 °C. The reaction progress was followed by TLC and after the time described on Table 1 the reaction mixture was extracted using ether (5 × 3 mL). The solvent was evaporated under reduced pressure and the residue was purified by column chromatography over silica gel eluting with hexanes or a mixture hexanes/ethyl acetate. For the synthesis of the vinyl tellurides analogs it was used 1.2 mmol of the alkyne. Spectral data of the products prepared are listed below.

*(2Z)-3-(Phenylseleno)prop-2-en-1-ol (**3a**)*[33]

Yield: 0.135g (63%). ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.54-7.43 (m, 2H); 7.27-7.22 (m, 3H); 6.58 (dt, *J* 9.4 and 1.4 Hz, 1H); 6.19 (dt, *J* 9.4 and 6.0 Hz, 1H); 4.24 (dd, *J* 6.0 and 1.4 Hz, 2H); 3.02 (br s, 1H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 134.54, 132.52, 131.81, 129.14, 127.07, 122.83, 61.26.

*2-(Phenylseleno)prop-2-en-1-ol (**4a**)*[33]

Yield: 0.051g (24%). ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.54-7.43 (m, 2H); 7.27-7.22 (m, 3H); 5.86 (s, 1H); 5.40 (s, 1H); 4.15 (s, 2H); 3.02 (br s, 1H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 141.37, 133.83, 129.24, 128.12, 127.72, 118.19, 66.25.

*(3Z)-2-Methyl-4-(phenylseleno)but-3-en-2-ol (**3b**)*[41]

Yield: 0.150g (62%). ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.57-7.51 (m, 2H); 7.28-7.24 (m, 3H); 6.43 (d, *J* 10.0 Hz, 1H); 6.00 (d, *J* 10.0 Hz, 1H); 2.15 (br s, 1H); 1.41 (s, 6H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 136.78, 132.82, 132.63, 128.99, 127.09, 120.59, 72.77, 29.48 (2C).

*(1Z)-3-Methyl-1-(phenylseleno)pent-1-en-3-ol (**3c**)*[41]

Yield: 0.230g (90%). ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.54-7.51 (m, 2H); 7.29-7.25 (m, 3H); 6.48 (d, *J* 10.1 Hz, 1H); 5.93 (d, *J* 10.1 Hz, 1H); 2.09 (br s, 1H); 1.66 (q, *J* 7.5 Hz, 2H); 1.35 (s, 3H); 0.96 (t, *J* 7.5 Hz, 3H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 135.49, 132.95, 132.39, 128.97, 127.03, 121.21, 75.34, 35.00, 27.16, 8.21.

*(Z)-(2-Phenylseleno-vinyl)-1-cyclohexanol (**3d**)*[39]

Yield: 0.229g (81%). ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.57-7.52 (m, 2H); 7.31-7.26 (m, 3H); 6.47 (d, *J* 9.8 Hz, 1H); 6.04 (d, *J* 9.8 Hz, 1H); 1.68-1.51 (m, 10H); 1.83 (br s, 1H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 136.31, 133.02, 132.66, 129.10, 127.21, 121.26, 73.92, 37.42 (2C), 25.31, 22.08.

*(2Z)-3-(Phenyltelluro)prop-2-en-1-ol (**3h**)*[41]

Yield: 0.169g (64%). ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.74-7.69 (m, 2H); 7.29-7.25 (m, 3H); 6.92 (dt, *J* 9.6 and 1.4 Hz, 1H); 6.53 (dt, *J* 9.6 and 5.0 Hz, 1H); 4.24-4.22 (m, 2H); 2.50 (br s, 1H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 138.99, 137.38, 136.53, 129.13, 127.50, 107.40, 64.07.

*2-(Phenyltelluro)prop-2-en-1-ol (**4h**)*[41]

Yield: 0.063g (24%). ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.82-7.76 (m, 2H); 7.33-7.20 (m, 3H); 6.25 (t, *J* 1.7 Hz, 1 H); 5.57 (t, *J* 1.7 Hz, 1H); 4.21 (s, 2H); 2.46 (br s, 1H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 138.96, 129.86, 129.33, 127.94, 123.31, 112.06, 69.19.

*(3Z)-2-Methyl-4-(phenyltelluro)but-3-en-2-ol (**3i**)*[41]

Yield: 0.187g (64%). ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.81-7.75 (m, 2H); 7.29-7.17 (m, 3H); 6.68 (d, *J* 9.8 Hz, 1H); 6.43 (d, *J* 9.8 Hz, 1H); 2.26 (br s, 1H); 1.36 (s, 6H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 141.28, 140.37, 137.75, 129.02, 127.42, 104.45, 73.31, 29.14.

*(1Z)-3-Methyl-1-(phenyltelluro)pent-1-en-3-ol (**3j**)*[41]

Yield: 0.211g (69%). ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.79-7.74 (m, 2H); 7.27-7.20 (m, 3H); 6.72 (d, *J* 10.0 Hz, 1H); 6.37 (d, *J* 10.0 Hz, 1H); 2.04 (br s, 1H); 1.63 (q, *J* 7.5 Hz, 2H); 1.31 (s, 3H); 0.95 (t, *J* 7.5 Hz, 3H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 140.50, 139.97, 137.60, 128.90, 127.27, 105.15, 75.51, 34.70, 26.79, 7.99.

*(Z)-(2-Phenyltelluro-vinyl)-1-cyclohexanol (**3k**)*[39]

Yield: 0.222g (67%). ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.79-7.74 (m, 2H); 7.28-7.16 (m, 3H); 6.69 (d, *J* 9.9 Hz, 1H); 6.47 (d, *J* 9.9 Hz, 1H); 1.67-1.25 (m, 10H); 1.87 (br s, 1H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 140.92, 137.87, 129.09, 127.42, 118.85, 104.95, 74.43, 36.82, 25.21, 21.80.

*(2Z)-1-(Butyltelluro)prop-2-en-1-ol (**3n**), 2-(Butyltelluro) prop-2-en-1-ol (**4n**)*[42]

Yield: 0.207g (85%). ^{1}H NMR (200 MHz, $CDCl_3$) δ 6.77 (ddd, *J* 9.6, 1.2 and 1.5 Hz, 0.1H); 6.40 (ddd, *J* 9.6, 5.2 and 5.4 Hz, 0.1H); 6.16 (dd, *J* 1.6 and 1.5 Hz, 0.9H); 5.52 (dd, *J* 1.3 and 1.2 Hz, 0.9H); 4.19 (s, 1.8H); 4.11 (dd, *J* 3.6 and 3.3 Hz, 0.2H); 2.72 (t, *J* 7.5 Hz, 1.8H); 2.60 (t, *J* 6.8 Hz, 0.2H); 1.85-1.70 (m, 2H); 1.45-1.25 (m, 2H); 0.96-0.89 (m, 3H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 137.41, 127.11, 122.73, 104.68, 70.12, 64.95, 34.03, 33.72, 25.08, 24.88, 13.39, 7.14, 6.11.

*(Z)-(2-Butyltelluro-vinyl)-benzene (**3p**)*[43]

Yield: 0.232g (80%). ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.35 (d, *J* 10.6 Hz, 1H); 7.31-7.13 (m, 5H); 6.90 (d, *J* 10.6 Hz, 1H); 2.62 (t, *J* 6.7 Hz, 2H); 1.75 (quint, *J* 6.7 Hz, 2H); 1.32 (sex, *J* 6.7 Hz, 2H); 0.85 (t, *J* 6.7 Hz, 3H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 138.89, 136.68, 128.23, 127.46, 127.13, 105.29, 33.87, 24.85, 13.35, 8.95.

*(E)-1-Phenyl-1,2-bis-(phenylseleno)ethene (**5a**)*[44]

Yield: 0.177g (85%). ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.52-7.09 (m, 15H); 7.02 (s, 1H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 139.51, 133.01, 132.08, 131.13, 130.62, 130.44, 129.24, 129.15, 128.59, 128.28, 128.24, 127.43, 127.40, 126.04.

*(E)-1-Phenyl-1,2-bis-(phenyltelluro)ethene (**5b**)*[39]

Yield: 0.211g (82%). ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.73 (d, *J* 6.8 Hz, 2H); 7.56 (d, *J* 6.8 Hz, 2H); 7.37 (s, 1H); 7.17-7.33 (m, 11H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 144.61, 139.06, 137.64, 129.67, 129.49, 128.70, 128.30, 128.20, 127.93, 127.61, 120.97, 116.03, 115.76, 115.09.

General procedure for the reuse of ionic liquid

The same procedure as for hydrochalcogenation of alkynes described before was followed. After work-up, [bmim]BF_4 was diluted with dichloromethane (3.0 mL) and filtered over Celite. The solution was dried over $MgSO_4$ and the volatiles were removed under vacuum. The recovered ionic liquid was reused for the next reaction.

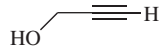
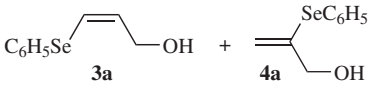
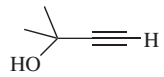
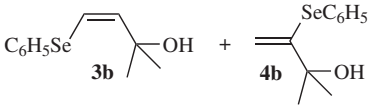
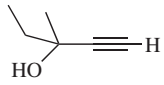
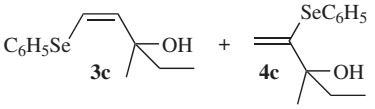
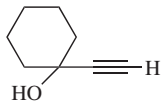
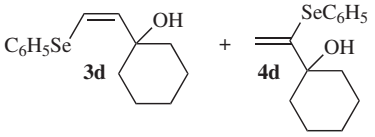
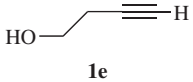
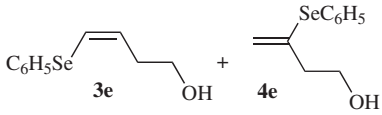
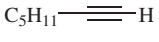
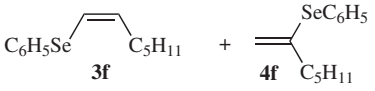
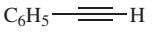
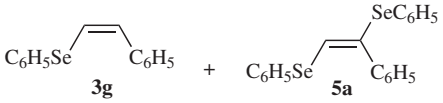
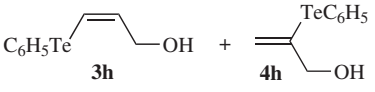
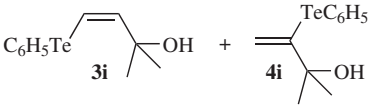
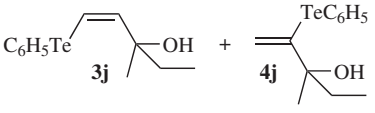
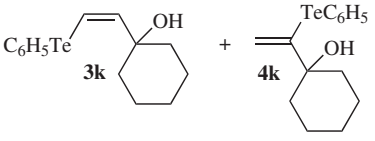
Results and Discussion

Initially, we chose propargyl alcohol (**1a**; 2.0 mmol) and diphenyl diselenide (**2a**; 0.5 mmol) to establish the best conditions for the hydroselenation reaction. We examined the temperature, amounts of IL and $NaBH_4$ and the use of N_2 atmosphere. It was found that using 1.2 mmol of $NaBH_4$ and 0.5 mL of IL at room temperature and under N_2 atmosphere, the reaction proceeded slowly furnishing the product in 30% yield after stirring for 26 h. However, when the mixture was heated at 60 °C, the desired products **3a** and **4a** were obtained in good yields (87%) after 6 h (Table 1, entry 1). When the same protocol was performed without N_2 it was observed, after 10 h, incomplete consume of **2a** and the products were isolated in 48% yield. When the reaction was performed in the presence of [bmim]BF_4 alone, without $NaBH_4$, no reaction took place in all conditions tested and the starting materials were recovered. Besides, using a smaller amount of $NaBH_4$ (1.0 mmol), the desired products **3a** and **4a** were obtained only in 52% yield. The use of a slighter amount of **1a** (1.5 mmol) afforded also lower yield of products (68%).

Since the best conditions were established, the protocol was extended to other alkynyl alcohols with diphenyl diselenide (Scheme 1). In all the studied cases, a mixture of (*Z*)-**3** and gem-**4** was obtained in good yields (Table 1, entries 1-5) and, except for homopropargyl alcohol **1e**, the anti-Markovnikov addut **3** was obtained in higher amount than the Markovnikov one **4** (Table 1, entry 5). For the reaction of phenylselenolate anions with sterically hindered alcohols, it was observed that steric factors are important, because both, the **3**:**4** ratio and the reaction time, increased with the R group size (Table 1, compare entries 2-4 with 1 and 5). This regioselectivity is similar to that reported for the methods which use organic solvents.[1,13-20] When the same protocol was applied to phenyl acetylene **1g**, (*E*)-1,2-bis-phenylseleno styrene **5a** was obtained in 85% yield after 3 h at 60 °C (Table 1, entry 7). This result is similar to that obtained under solvent-free conditions.[34]

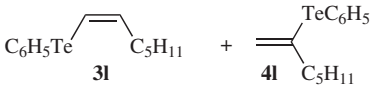
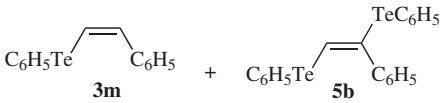
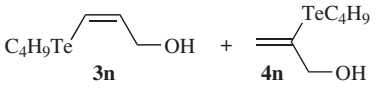
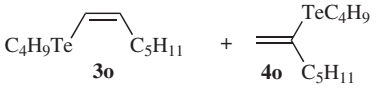
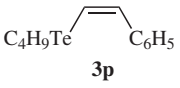
Aiming to extend the scope of this new method, we performed the hydrotelluration of terminal alkynes. Thus, when diphenyl ditelluride **2b** (0.5 mmol) reacted with propargyl alcohol **1a** (2.0 mmol) in the presence of $NaBH_4$ (1.2 mmol) and [bmim]BF_4 (0.5 mL), the respective vinyl tellurides **3h** and **4h** were obtained in 89% yield after stirring at 60 °C for 6.5 h. In contrast to the observed for the hydroselenation reaction, a large excess of alkyne is not necessary. Thus, when 1.2 mmol of propargyl alcohol **1a** reacted with 0.5 mmol of $C_6H_5TeTeC_6H_5$ under the same conditions, a mixture of the vinyl tellurides **3h** and **4h** was obtained in 88% yield after 7 h (**3h**:**4h** ratio = 73:27; Table 1, entry 8). Similarly to the selenium analogs, the reaction works well with other alkynols, giving preferentially the respective anti-Markovnikov adducts **3i-k** in good yields (Table 1, entries 9-11). Equally to the observed for diphenyl diselenide, the reaction with phenylacetylene gave the corresponding product **5b** in 82% yield, but with a ration (*Z*)-**3m**:**5b** = 5:95 (Table 1, entry 13). When dibutyl ditelluride **2c** was used as

Table 1. Hydrochalcogenation of alkynes using [bmim]BF_4 as recyclable solvent

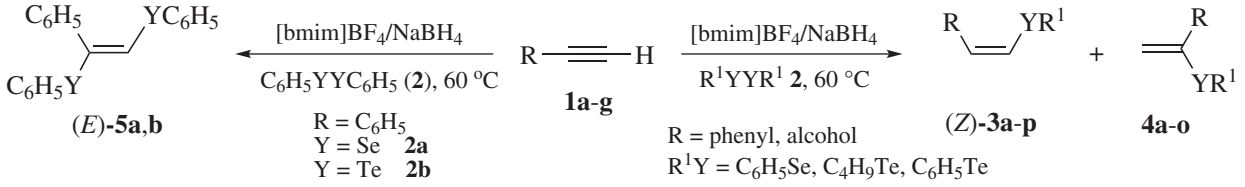
Entry	Alkyne **1**	Chalcogenide **2**	Products **3** + **4**	time (h)	Yield[a] (%)	Ratio[b] (*Z*)-**3**:**4**
1	 **1a**	$C_6H_5SeSeC_6H_5$ **2a**	 **3a** + **4a**	6	87	72:28
2	 **1b**	**2a**	 **3b** + **4b**	10	62	91:9
3	 **1c**	**2a**	 **3c** + **4c**	9	90	80:20
4	 **1d**	**2a**	 **3d** + **4d**	10	81	>95:5
5	 **1e**	**2a**	 **3e** + **4e**	6	74	44:56
6	 **1f**	**2a**	 **3f** + **4f**	9	trace	-
7	 **1g**	**2a**	 **3g** + **5a**	3	85	c
8	**1a**	$C_6H_5TeTeC_6H_5$ **2b**	 **3h** + **4h**	7	88	73:27
9	**1b**	**2b**	 **3i** + **4i**	10	64	90:10
10	**1c**	**2b**	 **3j** + **4j**	8	69	93:07
11	**1d**	**2b**	 **3k** + **4k**	11	67	94:06

[a]Yields of pure products isolated by column chromatography (hexanes/AcOEt) and identified by ^1H and ^{13}C NMR. [b]Determined by GC of the crude reaction mixture and confirmed after isolation of the individual isomers. [c]Obtained as mixture of (*Z*)-**3g** and (*E*)-**5a** (ratio 26:74). [d]Obtained as mixture of (*Z*)-**3m** and (*E*)-**5b** (ratio = 5:95).

Table 1. Continuation

Entry	Alkyne **1**	Chalcogenide **2**	Products **3** + **4**	time (h)	Yield[a] (%)	Ratio[b] (*Z*)-**3**:**4**
12	**1f**	**2b**	 **3l** + **4l**	12	trace	-
13	**1g**	**2b**	 **3m** + **5b**	6	82	d
14	**1a**	$C_4H_9TeTeC_4H_9$ **2c**	 **3n** + **4n**	5	85	15:85
15	**1f**	**2c**	 **3o** + **4o**	12	trace	-
16	**1g**	**2c**	 **3p**	6	80	100:0

[a]Yields of pure products isolated by column chromatography (hexanes/AcOEt) and identified by ^1H and ^{13}C NMR. [b]Determined by GC of the crude reaction mixture and confirmed after isolation of the individual isomers. [c]Obtained as mixture of (*Z*)-**3g** and (*E*)-**5a** (ratio 26:74). [d]Obtained as mixture of (*Z*)-**3m** and (*E*)-**5b** (ratio = 5:95).



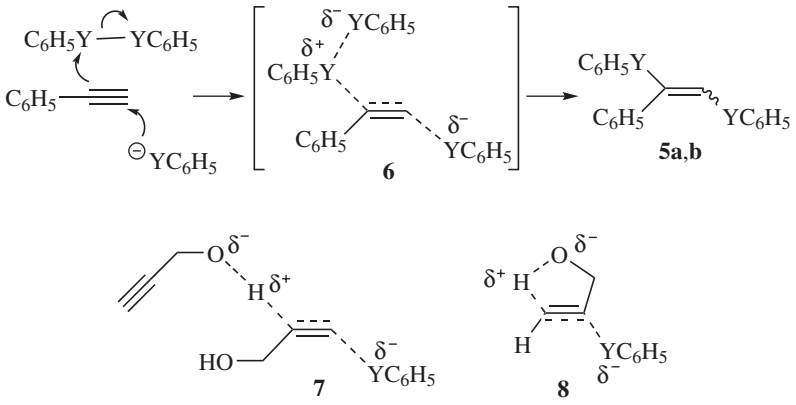
Scheme 1.

organochalcogenium source, the results were different of those observed with the diphenyl analogs **2a** and **2b**. In the reaction with propargyl alcohol **1a**, a mixture of vinyl tellurides **3n** and **4n** was obtained in 85% yield after 5 h at 60 °C, with the Markovnikov addut **4n** being predominant (**3n**:**4n** ratio = 15:85; Table 1, entry 14).

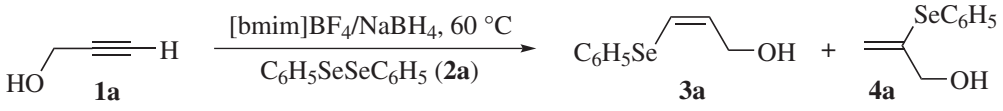
When **2c** reacted with phenylacetylene **1g** under the same conditions, only (*Z*)-(2-butyltelluro-vinyl)-benzene, **3p** was obtained in 80% yield (Table 1, entry 16). Unfortunately, no products were isolated when 1-heptyne **1f** was used as starting alkyne, with only trace amount being detected by GC (Table 1, entries 6, 12 and 15).

A plausible mechanism for the reaction of phenyl acetylene with diphenyl dichalcogenides using [bmim]BF_4 as solvent for formation of bis- and mono-phenylchalcogen alkenes respectively, is depicted on Scheme 2. The formation of bis-phenylchalcogen alkenes **5a** and **5b** can be attributed probably to the low solubility of the starting reagents **2a** and **2b** in the ionic liquid compared with **2c**, which makes the reaction behavior like a solvent-free one, with formation of an intermediate analogous to **6** (Scheme 2).[34] A free radical chain addition mechanism could also be involved.[45] For the propargylic alcohols, however, the formation of the respective bis-chalcogen alkenes were not observed. This fact suggests that in this case, the intermediates **7** and **8** could be involved in the formation of **3** and **4**, respectively.[46]

To check the efficacy of this method, a reuse study of the ionic liquid medium [bmim]BF_4 was carried out for the reaction showed in Scheme 3. After completion of the hydroselenation of propargyl alcohol **1a**, the reaction mixture was diluted with ethyl ether and the product was isolated. The ionic liquid was recovered, dried under vacuum and reused for further reactions. The ionic liquid maintained its good level of efficiency even after being reused three times (Table 2).



Scheme 2.



Scheme 3.

Table 2. Reuse of $[bmim]BF_4$ in hydroselenation of alkyne **1a**

Run	Yield **3a** + **4a** (%)[c]	Ionic Liquid recovery (%)
1[a]	87	99
2[b]	84	99
3[b]	83	98
4[b]	79	97

[a]Reactions were performed using alkyne **1a** (2.0 mmol), diphenyl diselenide **2a** (0.5 mmol) and $NaBH_4$ (1.2 mmol) in $[bmim]BF_4$ (0.5 mL) under N_2 atmosphere at 60 °C. [b]Recovered ionic liquid was used. [c]Obtained as a mixture of (*Z*)-**3a** and **4a** (ratio = 72:28).

Conclusions

We demonstrated the use of $NaBH_4$/$[bmim]BF_4$ as a reducing system for the addition of chalcogenolate anions to alkynyl alcohols and phenylacetylene to give selectively mono- and bis-organochalcogenides alkenes. This improved, simple, fast and clean protocol occurs under mild conditions, with non-aqueous work-up and the ionic liquid can be easily recovered and utilized for further reactions.

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References

1. Perin, G.; Lenardão, E. J.; Jacob, R. G.; Panatieri, R. B.; *Chem. Rev.* **2009**, *109*, 1277.
2. Freudendahl, D. M.; Shahzad, S. A.; Wirth, T.; *Eur. J. Org. Chem.* **2009**, 1649.
3. Beletskaya, I.; Moberg, C.; *Chem. Rev.* **2006**, *106*, 2320.
4. Zeni, G.; Lüdtke, D. S.; Panatieri, R. B.; Braga, A. L.; *Chem. Rev.* **2006**, *106*, 1032.
5. Back, T. G.; *Organoselenium Chemistry. A Practical Approach*, Oxford: New York, 2000.
6. Wirth, T.; *Organoselenium Chemistry - Modern Developments in Organic Synthesis. Topics in Current Chemistry 208*, Springer-Verlag: Heidelberg, 2000.
7. Petragnani, N.; Stefani, H. A.; *Tellurium in Organic Synthesis*, 2nd ed.; Academic Press: London, 2007.
8. Potapov, V. A.; Elokhina, V. N.; Larina, L. I.; Yaroshenko, T. I.; Tatarinova, A. A.; Amosova S. V.; *J. Organomet. Chem.* **2009**, *694*, 3679.
9. Saha, A.; Saha D.; Ranu B. C.; *Org. Biomol. Chem*. **2009**, *7*, 1652.
10. Alves D.; Luchese, C.; Nogueira, C. W.; Zeni, G.; *J. Org. Chem.* **2007**, *72*, 6726.
11. Nogueira, C. W.; Zeni, G.; Rocha, J. B. T.; *Chem. Rev.* **2004**, *104*, 6255.
12. Mugesh, G.; du Mont, W.-W.; Sies, H.; *Chem. Rev.* **2001**, *101*, 2125.
13. Zeni, G.; Stracke, M. P.; Nogueira, C. W.; Braga, A. L.; Menezes, P. H.; Stefani, H. A.; *Org. Lett.* **2004**, *6*, 1135.
14. Dabdoub, M. J.; Baroni, A. C. M.; Lenardão, E. J.; Gianeti, T. R.; Hurtado, G. R.; *Tetrahedron* **2001**, *57*, 4271.
15. Barros, O. S. D.; Lang, E. S.; de Oliveira, C. A. F.; Peppe, C.; Zeni, G.; *Tetrahedron Lett.* **2002**, *43*, 7921.
16. Comasseto, J. V.; *J. Organomet. Chem*. **1983**, *253*, 131.
17. Dabdoub, M. J.; Cassol, T. M.; Batista, A. C. F.; *Tetrahedron Lett.* **1996**, *37*, 9005.

18. Wang, Z.; Tang, R.; Luo, P.; Deng, C.; Zhong, P.; Li, J.; *Tetrahedron* **2008**, *64*, 10670.
19. Trofimov, B. A.; Gusarova, N. K.; Tatarinova, A. A.; Potapov, V. A.; Sinegovskaya, L. M.; Amosova, S. V.; Voronkov, M. G.; *Tetrahedron* **1988**, *44*, 6739.
20. Ananikov, V. P.; Malyshev, D. A.; Beletskaya, I. P.; Aleksandrov, G. G.; Eremenko, I. L.; *J. Organomet. Chem*. **2003**, *679*, 162.
21. Jain, N.; Kumar, A.; Chauhan, S.; Chauhan, S. M. S.; *Tetrahedron* **2005**, *61*, 1015.
22. Dupont, J.; Souza, R. F.; Suarez, P. A. Z.; *Chem. Rev.* **2002**, *102*, 3667.
23. Dupont, J.; Consorti, C. S.; Spencer, J.; *J. Braz. Chem. Soc.* **2000**, *11*, 337.
24. Consorti, C. S.; Souza, R. F.; Dupont, J.; Suarez, P. A. Z.; *Quim. Nova* **2001**, *24*, 830.
25. Wasserscheid, P.; Welton, T.; *Ionic Liquids in Synthesis*, Wiley-VCH Verlag: New York, 2002.
26. Welton, T.; *Chem. Rev.* **1999**, *99*, 2071.
27. Wassercheid, P.; Keim, W.; *Angew. Chem. Int. Ed.* **2000**, *39*, 3772.
28. Davis Jr, J. H.; Fox, P. A.; *Chem. Commun.* **2003**, 1209.
29. Cai, M.; Wang, Y; Hao, W.; *Green Chem*. **2007**, *9*, 1180.
30. Pârvulescu, V. I.; Hardacre, C.; *Chem. Rev*. **2007**, *107*, 2615.
31. Schrekker, H. S.; Silva, D. O.; Gelesky, M. A.; Stracke, M. P.; Schrekker, C. M. L.; Gonçalves, R. S.; Dupont, J.; *J. Braz. Chem. Soc.* **2008**, *19*, 426.
32. Singh, R.; Sharma, M.; Mamgain, R.; Rawat, D. S.; *J. Braz. Chem. Soc.* **2008**, *19*, 357.
33. Lenardão, E. J.; Dutra, L. G.; Saraiva, M. T.; Jacob, R. G.; Perin, G.; *Tetrahedron Lett*. **2007**, *48*, 8011.
34. Perin, G.; Jacob, R. G.; Dutra, L. G.; Azambuja, F.; Santos, G. F. F.; Lenardão, E. J.; *Tetrahedron Lett.* **2006**, *47*, 935.
35. Perin, G.; Mendes, S. R.; Silva, M. S.; Lenardão, E. J.; Jacob, R. G.; Santos, P. C. S.; *Synth. Commun.* **2006**, *36*, 2587.
36. Perin, G.; Jacob, R. G.; Botteselle, G. V.; Kublik, E. L.; Lenardão, E. J.; Cella, R.; Santos, P. C. S.; *J. Braz. Chem. Soc.* **2005**, *16*, 857.
37. Perin, G.; Jacob, R. G.; Azambuja, F.; Botteselle, G. V.; Siqueira, G. M.; Freitag, R. A.; Lenardão, E. J.; *Tetrahedron Lett.* **2005**, *46*, 1679.
38. Lenardão, E. J.; Silva, M. S.; Mendes, S. R.; Azambuja, F.; Jacob, R. G.; Santos, P. C. S.; Perin, G.; *J. Braz. Chem. Soc.* **2007**, *18*, 943.
39. Lenardão, E. J.; Silva, M. S.; Sachini, M.; Lara, R. G.; Jacob, R. G.; Perin, G.; *ARKIVOC* **2009**, *xi*, 221.
40. Silveira, C. C.; Perin, G.; Braga, A. L.; *J. Chem. Res.-S* **1994**, 492.
41. Silveira, C. C.; Mendes, S. R.; Rosa, D. D.; Zeni, G.; *Synthesis* **2009**, 4015.
42. Raminelli, C.; Silva, N. C.; Santos, A. A.; Porto, A. L. M.; Andrade, L. H.; Comasseto, J. V.; *Tetrahedron* **2005**, *61*, 409.
43. Dabdoub, M. J.; Dabdoub, V. B.; Comasseto, J. V.; Petragnani, N.; *J. Organomet. Chem.* **1986**, *308*, 211.
44. Peppe, C.; Lang, E. S.; Ledesma, G. N.; Castro, L. B.; Barros, O. S. R.; Mello, P. A.; *Synlett* **2005**, 3091.
45. Keppler, A. F.; Cerchiaro, G.; Augusto, O.; Miyamoto, S.; Prado, F.; Di Mascio, P.; Comasseto, J. V.; *Organometallics* **2006**, *25*, 5059.
46. Dabdoub, M. J.; Dabdoub, V.; *Tetrahedron* **1995**, *51*, 9839.

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