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Reactivity of 3-silyloxy-1,4-enynes: Gold(III)-catalyzed regioselective nucleophilic substitution

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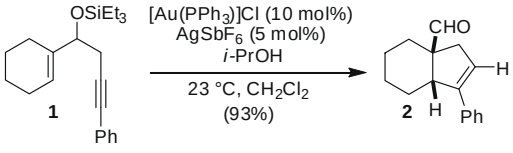
ABSTRACT

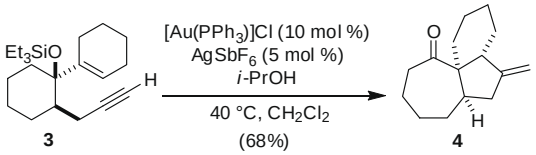
Gold-catalyzed reactions of 3-silyloxy-1,4-enynes with alcohols afford primary, secondary, and tertiary pent-2-en-4-ynyl ethers in moderate to excellent yields. The substitution proceeds with high regioselectivity. An initial cyclization providing five-membered carbocycles instead was not observed under the reaction conditions. Control experiments show that these reactions are also catalyzed by Brønsted- and Lewis-acids, although scope and yields are markedly reduced.

1. Introduction

Within the rapidly developing field of catalysis involving homogeneous gold-complexes as carbophilic Lewis-acids [1], the diverse reactivity of enynes has attracted particularly much interest [2]. The two most prominent classes that were employed in catalyzed cycloisomerization reactions are 1,5-enynes [3] and 1,6-enynes [4]. Recently, we have launched a research program that aims to systematically reveal the noble metal-catalyzed reactivity of 1,n-enynes bearing either a free or a protected hydroxyl group at the 3-position [5,6]. In 2007, we reported the construction of highly substituted cyclopentenes from 3-silyloxy-1,5-enynes using catalytic amounts of [(Ph_3P)AuSbF_6] and *i*-PrOH as a proton source [7]. This product formation was explained by assuming a cascade reaction consisting of 6-*endo* carbocyclization and pinacol-type 1,2-migration. For example, reaction of enyne **1** in CH_2Cl_2 at room temperature produced the bicyclic compound **2** in good yield (93%) (Eq. (1)). In a related cascade reaction, 3-silyloxy-1,6-enynes can react through a pathway combining an initial 6-*exo* carbocyclization and a subsequent pinacol rearrangement (Eq. (2)) [8]. In addition, 3-silyloxy-1,6-enynes were found to undergo a sequence of heterocyclization followed by a Claisen rearrangement depending on the substitution pattern of the substrates and the electronic properties of the gold-bound phosphane ligand. Despite the synthetic value of these reactions, the reactivity of 3-silyloxy-1,4-enynes in the presence of gold catalysts was not further investigated. We disclose herein our observations when using 3-silyloxy-1,4-enynes as substrates in gold-catalyzed reactions.



(1)



(2)

2. Results and discussion

We now report a regioselective nucleophilic substitution that provides access to 5-alkoxy-pent-3-en-1-ynes from 3-silyloxy-1,4-enynes and alcohols. In this work, gold(III) complexes are employed as precatalysts to activate the propargylic alcohol moiety that is protected as a silyl ether. While gold(III) complexes have received recent attention as catalysts for Friedel-Crafts-type alkylations with benzylic alcohols and benzylic acetates,[9] their

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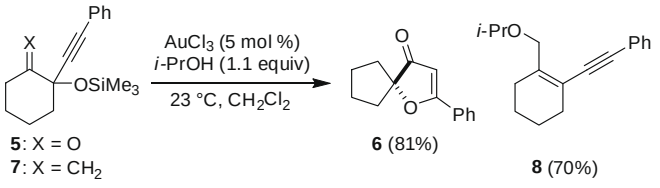
use for the direct substitution of propargylic alcohols is rare. In this context, Campagne and co-workers developed a protocol utilizing $Na[AuCl_4]$ as catalyst for an efficient propargylic substitution with various C-, O-, and S-nucleophiles [10]. Dyker and co-workers used $AuCl_3$ for the efficient propargylation of electron-rich arenes.[11] Further catalytic methodologies [12] for the propargylic substitution take use of ruthenium [13], rhenium [14], bismuth [15], or copper [16] catalysts. Simple Brønsted-acids such as *p*-toluenesulfonic acid were also found to catalyze the direct substitution of the hydroxyl group in propargylic alcohols [17].

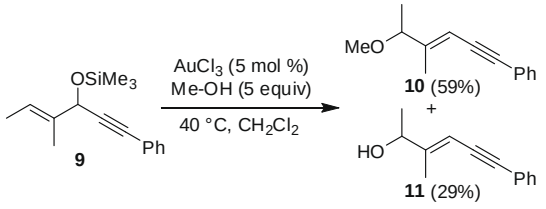
We began our investigation into the reactivity of 3-silyloxy-1,4-enynes by utilizing catalyst and reaction parameters optimized for the conversion of silyl ether **5** [18]. While in the case of **5** the internal oxygen nucleophile facilitates an initial cyclization that finally leads to the formation of spirocyclic 3-furanone **6**, a related 5-*endo* cyclization was not observed when using the analogous methylene-containing silyl ether **7**. Instead, activation by $AuCl_3$ afforded enyne **8** in 70% yield as the product of an exclusive nucleophilic substitution that proceeds with excellent regioselectivity (Scheme 1) [19]. The reaction of substrate **7** was monitored by ^1H NMR spectroscopy indicating that substitution was the sole pathway (besides partial cleavage of the silyl ether). Unfortunately, the monitoring did not detect any trace products that might have resulted from a C–C-bond forming cyclization as envisaged initially. Although this catalyst system did prove efficient with the conversion of a variety of 3-silyloxy-1,4-enynes, the scope was somewhat limited due to the fact that the etherification products were typically accompanied by significant amounts of the corresponding alcohols. As exemplified for the reaction of 3-silyloxy-1,4-enyne **9** (Scheme 2), both methyl ether **10** and alcohol **11** were obtained in 59% yield and 29% yield, respectively. This observation might be attributed to the hygroscopicity of $AuCl_3$ under the open-flask conditions employed for the described transformations (see Section 4).

An extensive screen with commercially available gold(I) and gold(III) catalysts produced $K[AuCl_4]$ to be the catalyst system of choice for the conversion of 3-trimethylsilyloxy-1-phenylhex-4-en-1-yne (**12**) into (5-methoxyhex-3-en-1-ynyl)benzene (**13**) [5mol%K[AuCl4], 5 equiv. MeOH, 40 °C, CH_3CN/CH_2Cl_2 (1/10), 98%] (Scheme 3). Under these reaction conditions, the propargylic substitution was performed under experimentally simple open-flask conditions. Unlike in the case of $AuCl_3$, the introduction of water was not observed. Other gold catalysts such as $HAuCl_4 \cdot 4H_2O$, AuCl, and $[(Me_3P)AuSbF_6]$ resulted in markedly reduced yields (or full recovery of the starting material). $PtCl_2$ (5 mol%, 120 °C, toluene) gave the product of the regioselective substitution in 35% yield. Interestingly, Brønsted- and Lewis-acid catalysts [e.g., $Bi(OTf)_3$ (67%), *p*-TsOH (61%), and HBF_4 (52%)] were effective, but they did not exhibit the wide applicability observed in the case of $K[AuCl_4]$.

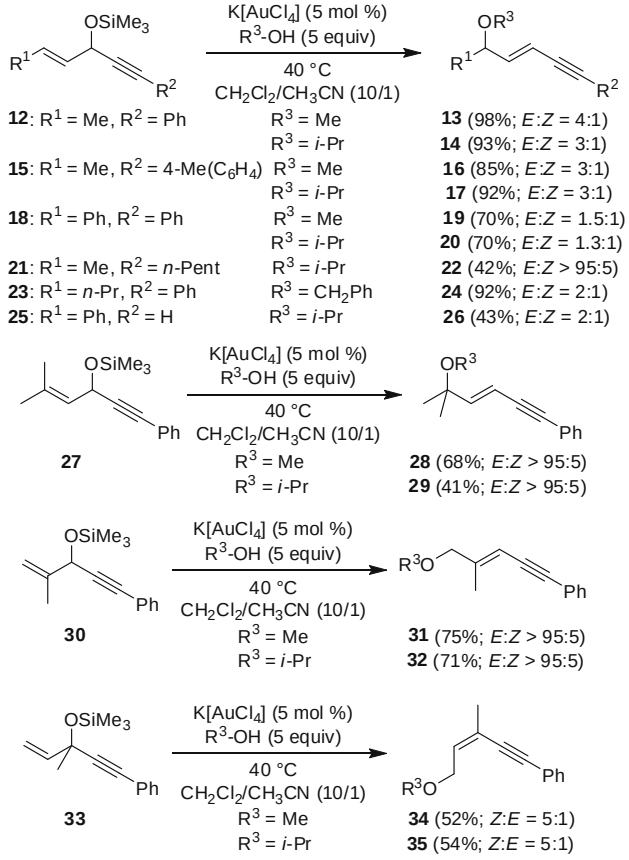
The scope of the reaction of 3-silyloxy-1,4-enynes with alcohols (5 equiv) in the presence of 5 mol% $K[AuCl_4]$ is summarized in Scheme 3. At 40 °C, reactions of 3-silyloxy-1,4-enynes bearing a 1,2-disubstituted alkene moiety with various alcohols provided the corresponding ethers with excellent regioselectivity and good yields (42–98%). In general, the products of the nucleophilic substitution were obtained as an inseparable mixture of cis- and trans-double bond isomers. The presence of both aryl and alkyl substituents at the alkyne terminus was tolerated, albeit with a



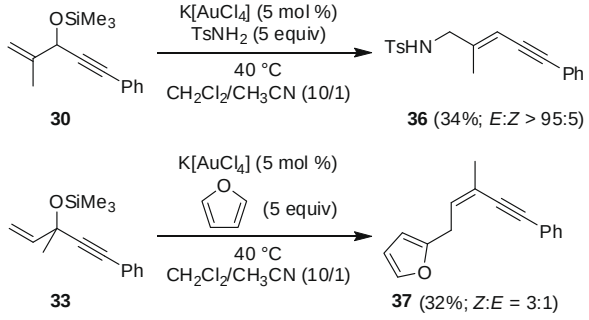
Scheme 1. Comparison between the reactivity of 5 and 7 in the presence of $AuCl_3$.



Scheme 2. Use of $AuCl_3$ in the regioselective substitution of 3-silyloxy-1,4-enynes.



Scheme 3. Propargylic substitution of 3-silyloxy-1,4-enynes with alcohols catalyzed by $K[AuCl_4]$.



Scheme 4. Nucleophilic substitution with N- and C-nucleophiles.

reduced yield for substrate **21** (R^2 = *n*-Pent). The reaction of terminal alkynes such as **25** was low-yielding and slow. Enyne **27** containing a trisubstituted alkene reacted to give the tertiary ether **28** in moderate yield, as did substrates containing a different alkene substitution pattern.

Several additional observations merit note. Our current results do not question the mechanistic details of this substitution that may involve a S_N1- or S_N2'-like nucleophilic attack. Nevertheless, the triple bond was beneficial to the reaction outcome since either no conversion or complete decomposition was obtained in the absence of the propargylic alcohol moiety. For example, 1-trimethylsilyloxy-1-phenylprop-2-ene decomposed under the reaction conditions while 3-trimethylsilyloxy-oct-1-ene did not react. It was not necessary to take special precautions to exclude air and moisture from the reaction mixture. The reactions shown in Scheme 3 were remarkably regioselective, producing primary, secondary, and tertiary ethers without the formation of any regioisomer. As a consequence of silyl ether cleavage, the corresponding 3-hydroxy-1,4-enynes were occasionally identified as significant by-products formed during the course of the reaction. Nevertheless, the use of 3-hydroxy-1,4-enynes instead of 3-silyloxy-1,4-enynes produced diminished yields (e.g., 78% for **14**) for the substitution whereas the reaction was slowed markedly. With the corresponding propargylic acetate, substitution product **14** was obtained in 19% yield (*E*/*Z* = 2/1) under the reaction conditions accompanied by a variety of undefined decomposition products. Enol ether or acetal formation [20] resulting from the direct addition of the alcohols onto the alkyne moiety was not observed. Other nucleophiles such as tosylamide [19] and furan reacted as well with 3-silyloxy-1,4-enynes under gold catalysis; in these cases, the substitution reactions proceeded with much lower yields (Scheme 4).

3. Conclusion

In summary, we have studied gold-catalyzed reactions of 3-silyloxy-1,4-enynes with alcohols. An attempted C–C-bond forming cyclization failed, which clearly excludes 3-silyloxy-1,4-enynes as precursors for five-membered carbocycles. Instead, a highly regioselective nucleophilic substitution was observed in the presence of gold(III)-precatalysts. This reaction provides access to primary, secondary, and tertiary pent-2-en-4-ynyl ethers.

4. Experimental

4.1. General experimental details

All commercially available chemicals were used without further purification. The 3-silyloxy-1,4-enynes were synthesized from the corresponding enones by nucleophilic addition of the lithiated acetylenes followed by silyl protection of the hydroxyl group. All the substitution reactions were performed under open-flask conditions without the use of an inert gas. For all compounds, the assignment of double bond geometry is based on NOESY data. The ^{13}C NMR data given show the signals of the major diastereoisomer unless otherwise noted.

4.2. General procedure for the substitution

4.2.1. (E/Z)-(5-(Benzyloxy)oct-3-en-1-ynyl)benzene (**24**)

85.0 mg of (*E*)-trimethyl(1-phenyloct-4-en-1-yn-3-yloxy)silane (0.31 mmol) were dissolved in 3 mL CH_2Cl_2 and 0.16 mL benzylic alcohol (169 mg, 1.56 mmol) were added. A solution of 5.89 mg $KAuCl_4$ (0.02 mmol) 1 m in MeCN was added and the reaction mixture was stirred at 40 °C for 1.5 h. The solvent was evaporated and the residue was purified by flash-chromatography on silica (pentanes/EtOAc = 98:2). The product was isolated as a pale yellow oil (82.8 mg, 0.29 mmol, 92%) containing the *E* and *Z* diastereoisomer of **24** in a ratio of 2:1 (according to ^1H NMR). ^1H NMR (250 MHz, $CDCl_3$) δ *0.88–0.95* (m, 3H *E*-isomer, 1.5H *Z*-isomer), 1.26–1.81 (m, 4H, *E*-isomer, 2H *Z*-isomer), 3.81–3.89 (m, 1H *E*-isomer), 4.36–4.70 (m, 2H *E*-isomer, 1H *Z*-isomer), 5.87–5.93 (m, 1H *E*-isomer, 0.5H *Z*-isomer), 6.16 (dd, *J* = 16.0, 7.4 Hz, 1H *E*-isomer), 7.27–7.46 (m, 10H *E*-isomer, 5H *Z*-isomer); ^{13}C NMR (*E*-isomer, 90.6 MHz, $CDCl_3$) δ 14.1, 18.7, 37.8, 70.6, 79.3, 87.5, 90.1, 111.79, 123.4, 127.7, 127.9, 128.4, 128.5, 128.5, 131.7, 138.7, 144.4; MS (70 eV) *m*/*z* (%): 290 (2) [M^+], 247 (26), 204 (15), 91 (100), 71 (31). HRMS Calc. for $C_{21}H_{22}O$: 290.1671. Found: 290.1667.

4.3. Characterization data for the substitution products

4.3.1. (E/Z)-(5-Methoxyhex-3-en-1-ynyl)benzene (**13**)

^1H NMR (360 MHz, $CDCl_3$) δ 1.28 (d, *J* = 6.4 Hz, 3H, *E*-isomer), 1.31 (d, *J* = 6.6 Hz, 0.69H, *Z*-isomer), 3.32 (s, 3H, *E*-isomer), 3.35 (s, 0.69H, *Z*-isomer), 3.78–3.85 (m, 1H, *E*-isomer), 4.40–4.48 (m, 0.23H, *Z*-isomer), 5.85–5.91 (m, 1H *E*-isomer, 0.46H *Z*-isomer), 6.11 (dd, *J* = 7.0, 15.9 Hz, 1H, *E*-isomer), 7.30–7.34 (m, 3H *E*-isomer, 0.70H *Z*-isomer), 7.43–7.45 (m, 2H *E*-isomer, 0.46H *Z*-isomer); ^{13}C NMR (*E*-isomer, 90.6 MHz, $CDCl_3$) δ 21.2, 56.5, 77.6, 87.4, 90.0, 111.1, 123.4, 128.4, 128.5, 131.7, 145.0. MS (70 eV) *m*/*z* (%): 186 (29) [M^+], 171 (100), 153 (21), 128 (37), 115 (25). HRMS Calc. for $C_{13}H_{14}O$: 186.1045. Found: 186.1048.

4.3.2. (E/Z)-(5-Isopropoxyhex-3-en-1-ynyl)benzene (**14**)

^1H NMR (360 MHz, $CDCl_3$) δ *1.14–1.21* (m, 6H *E*-isomer, 1.8H *Z*-isomer), 1.25–1.30 (m, 3H *E*-isomer, 0.9H *Z*-isomer), 3.63–3.75 (m, 1H *E*-isomer, 0.3H *Z*-isomer), 4.01–4.08 (m, 1H, *E*-isomer), 4.61–4.70 (m, 0.3H, *Z*-isomer), 5.77 (d, *J* = 11.1 Hz, 0.3H, *Z*-isomer), 5.85–5.92 (m, 1H *E*-isomer, 0.3H *Z*-isomer), 6.15 (dd, *J* = 6.8, 15.9 Hz, 1H, *E*-isomer), 7.29–7.34 (m, 3H *E*-isomer, 0.9H *Z*-isomer), 7.42–7.44 (m, 2H *E*-isomer, 0.6H *Z*-isomer); ^{13}C NMR (*E*-isomer, 90.6 MHz, $CDCl_3$) δ 21.4, 21.8, 23.4, 69.1, 72.9, 87.6, 89.8, 109.9, 123.4, 128.4, 128.5, 131.5, 146.3. MS (70 eV) *m*/*z* (%): 214 (12) [M^+], 199 (28), 171 (51), 157 (100), 128 (51). HRMS Calc. for $C_{13}H_{14}O$: 214.1358. Found: 214.1357.

4.3.3. (E/Z)-1-(5-Methoxyhex-3-en-1-ynyl)-4-methylbenzene (**16**)

^1H NMR (360 MHz, $CDCl_3$) δ 1.28 (d, *J* = 6.4 Hz, 3H *E*-isomer), 1.31 (d, *J* = 6.4 Hz, 1H *Z*-isomer), 2.33 (s, 3H *E*-isomer), 2.34 (s, 1H *Z*-isomer), 3.31 (s, 3H *E*-isomer), 3.35 (s, 1H *Z*-isomer), 3.78–3.85 (m, 1H *E*-isomer), 4.40–4.48 (m, 0.3H *Z*-Isomer), 5.84–5.89 (m, 1H *E*-isomer, 0.6H *Z*-isomer), 6.10 (dd, *J* = 15.9, 7.2 Hz, 1H *E*-isomer), 7.11–7.27 (m, 4H *E*-isomer, 1.3H *Z*-isomer), ^{13}C NMR (*E*-isomer, 90.6 MHz, $CDCl_3$) δ 21.2, 21.4, 56.5, 77.6, 87.0, 90.2, 111.2, 123.2, 128.4, 128.7, 129.3, 132.2, 138.1, 144.8; MS (70 eV) *m*/*z* (%):200 (26) [M^+], 185 (100), 169 (11), 153 (14), 142 (23), 129 (15), 115 (15). HRMS Calc. for $C_{14}H_{16}O$: 200.1201. Found: 200.1204.

4.3.4. (E/Z)-1-(5-Isopropoxyhex-3-en-1-ynyl)-4-methylbenzene (**17**)

^1H NMR (360 MHz, $CDCl_3$) δ*1.13–1.18* (m, 6H *E*-isomer, 2H *Z*-isomer), 1.20 (d, *J* = 6.1 Hz, 1H *Z*-isomer), 1.26 (d, *J* = 6.6, 3H *E*-isomer), 1.28 (d, *J* = 6.6, 1H *Z*-isomer), 2.33 (s, 3H *E*-isomer), 2.34 (s, 1H *Z*-isomer), 3.61–3.77 (m, 1H *E*-isomer, 0.3H *Z*-isomer), 4.00–4.08 (m, 1H *E*-isomer), 4.62–4.70 (m, 0.3H *Z*-isomer),5.75–5.90 (m, 1H *E*-isomer, 0.6H *Z*-isomer), 6.14 (dd, *J* = 15.9, 6.8 Hz, 1H *E*-isomer), 7.10–7.26 (m, 4H *E*-isomer, 1.3H *Z*-isomer), ^{13}C NMR (*E*-isomer, 90.6 MHz, $CDCl_3$) δ 21.3, 21.9, 22.0, 23.4, 69.1, 73.0, 87.3, 90.0, 110.0, 123.3, 128.3, 128.7, 129.2, 132.2, 138.1, 146.2; MS (70 eV) *m*/*z* (%): 228 (12) [M^+], 213 (20), 185 (46), 171 (100), 153 (17),

143 (34), 128 (35), 115 (20). HRMS Calc. for $C_{16}H_{20}O$: 228.1514. Found: 228.1511.

*4.3.5. (E/Z)-(5-Methoxypent-3-en-1-yne-1,5-diyl)dibenzene (**19**)*

^{1}H NMR (250 MHz, $CDCl_3$) δ 3.37 (s, 3H, *E*-isomer), 3.44 (s, 2.1H, *Z*-isomer), 7.73 (dd, *J* = 1.1, 6.5 Hz, 1H, *E*-isomer), 5.48 (d, *J* = 8.9 Hz, 0.7H, *Z*-isomer), 5.88–6.11 (m, 1H *E*-isomer, 1.4H *Z*-isomer), 6.29 (dd, *J* = 6.5 15.8 Hz, 1H, *E*-isomer), 7.29–7.52 (m, 10H *E*-isomer, 7H *Z*-isomer); ^{13}C NMR (*E*-isomer, 62.9 MHz, $CDCl_3$) δ 56.7, 83.7, 87.5, 90.6, 111.2, 123.3, 127.1, 128.1, 128.4, 128.6, 128.7, 131.7, 141.0, 143.3. MS (70 eV) *m*/*z* (%): 248 (32) [M^+], 233 (100), 215 (66), 202 (38). HRMS Calc. for $C_{18}H_{16}O$: 248.1201. Found: 248.1203.

*4.3.6. (E/Z)-(5-Isopropoxypent-3-en-1-yne-1,5-diyl)dibenzene (**20**)*

^{1}H NMR (250 MHz, $CDCl_3$) δ 1.17 (d, *J* = 6.2 Hz, 3 H, *E*-isomer), 1.22–1.28 (m, 3H *E*-isomer, 4.8H *Z*-isomer), 3.66–3.85 (m, 1H *E*-isomer, 0.8H *Z*-isomer), 4.97 (dd, *J* = 1.3, 6.3 Hz, 1H, *E*-isomer), 5.64 (d, *J* = 9.0 Hz, 0.8H, *Z*-isomer), 5.82–6.10 (m, 1H *E*-isomer, 1.6H *Z*-isomer), 6.31 (dd, *J* = 6.3, 16.0 Hz, 1H, *E*-isomer), 7.28–7.50 (m, 10H *E*-isomer, 8H *Z*-isomer); ^{13}C NMR (*E*-isomer, 62.9 MHz, $CDCl_3$) δ 22.3, 22.6, 69.3, 79.0, 85.9, 87.7, 95.7, 110.5, 123.4, 126.5, 127.9, 128.3, 128.6, 131.6, 141.2, 144.5. MS (70 eV) *m*/*z* (%): 276 (18) [M^+], 233 (100), 215 (57), 205 (45). HRMS Calc. for $C_{20}H_{20}O$: 276.1514. Found: 276.1510.

*4.3.7. (E)-2-Isopropoxy-5-methylundec-3-en-5-yne (**22**)*

^{1}H NMR (360 MHz, $CDCl_3$) δ 0.90 (t, *J* = 7.2 Hz, 3H), 1.10 (d, *J* = 6.1 Hz, 3H), 1.13 (t, *J* = 6.1 Hz, 3H), 1.21 (d, *J* = 6.6 Hz, 3H), 1.28−1.42 (m, 4H), 1.48−1.56 (m, 2H), 2.29 (td, *J* = 7.2 Hz, *J* = 2.0 Hz, 2H), 3.62 (sep, *J* = 6.1 Hz, 1H), 3.91−4.00 (m, 1H), 5.61 (dd, *J* = 15.9 Hz, *J* = 1.1 Hz, 1H), 5.94 (dd, *J* = 15.9 Hz, *J* = 7.0 Hz, 1H); ^{13}C NMR (90.6 MHz, $CDCl_3$) δ 14.0, 19.5, 21.7, 22.0, 22.3, 23.3, 28.5, 31.2, 68.7, 72.9, 78.5, 91.0, 110.5, 144.6; MS (70 eV) *m*/*z* (%): 208 (5), 151 (14), 109 (100), 95 (26), 81 (27). HRMS Calc. for $C_{14}H_{24}O$: 208.1827. Found: 208.1828.

*4.3.8. (E/Z)-(1-isopropoxypent-2-en-4-ynyl)benzene (**26**)*

^{1}H NMR (360 MHz, CDCl3) δ 1.14 (d, *J* = 6.1 Hz, 3H *E*-isomer), 1.19–1.22 (m, 3H *E*-isomer, 1.8H *Z*-isomer), 1.23 (d, *J* = 6.1 Hz 3H *Z*-isomer), 2.87 (d, *J* = 2.3 Hz, 1H *E*-isomer), 3.19 (dd, *J* = 2.3, 0.9, 0.6H *Z*-isomer), 3.60–3.69 (m, 1H *E*-isomer), 3.70–3.79 (m, 0.6H *Z*-isomer), 4.91 (dd, *J* = 6.0, 1.2, 1H, *E*-isomer), 5.53–5.56 (m, 1H, *E*-isomer), 5.58–5.62 (m, 0.6H, *Z*-isomer), 5.69–5.75 (m, 1H, *E*-isomer), 6.05–6.11 (m, 0.6H, *Z*-isomer), 6.31 (dd, *J* = 15.9, 6.0, 1H, *E*-isomer), 7.24–7.44 (m, 5H *E*-isomer, 3H *Z*-isomer); ^{13}C NMR (90.6 MHz, $CDCl_3$) δ 22.2, 22.6, 69.4, 78.1, 78.7, 82.7, 109.2, 126.5, 127.1, 127.9, 128.7, 140.8, 146.3; MS (70 eV) *m*/*z* (%): 200 (5) [M^+], 185 (5), 157 (57), 141 (76), 129 (83), 115 (100), 105 (54), 91 (30), 77 (32), 63 (14), 51 (19).

*4.3.9. (E)-1-(5-Methoxy-5-methylhex-3-en-1-ynyl)benzene (**28**)*

^{1}H NMR (360 MHz, $CDCl_3$) δ 1.32 (s, 6H), 3.21 (s, 3H), 5.84 (d, *J* = 16.4 Hz, 1H), 6.21 (d, *J* = 16.4 Hz, 1H), 7.28−7.33 (m, 3H), 7.41−7.47 (m, 2H); ^{13}C NMR (90.6 MHz, $CDCl_3$) δ = 25.7, 50.8, 75.2, 87.6, 90.1, 109.6, 123.5, 128.3, 128.4, 131.6, 148.7; MS (70 eV) *m*/*z* (%): 200 (25) [M^+], 185 (100), 170 (23), 152 (38), 141 (14). HRMS Calc. for $C_{14}H_{16}O$: 200.1201. Found: 200.1201.

*4.3.10. (E)-1-(5-Isopropoxy-5-methylhex-3-en-1-ynyl)benzene (**29**)*

^{1}H NMR (360 MHz, $CDCl_3$) δ 1.14 (d, *J* = 6.2 Hz, 6H), 1.32 (s, 6H), 3.70 (sep, *J* = 6.2 Hz, 1H), 5.82 (d, *J* = 16.4 Hz, 1H), 6.28 (d, *J* = 16.4 Hz, 1H), 7.28−7.35 (m, 3H), 7.41−7.46 (m, 2H); ^{13}C NMR (90.6 MHz, $CDCl_3$) δ 25.2, 26.9, 65.3, 75.3, 87.8, 89.9, 108.9, 123.5, 128.3, 128.4, 131.6, 150.0; MS (70 eV) *m*/*z* (%): 228 (8) [M^+], 213 (17), 171 (100), 152 (15), 128 (16). HRMS Calc. for $C_{16}H_{20}O$: 228.1514. Found: 228.1515.

*4.3.11. (E)-(5-Methoxy-4-methylpent-3-en-1-ynyl)benzene (**31**)*

^{1}H NMR (250 MHz, $CDCl_3$) δ 1.97 (s, 3H), 3.34 (s, 3H), 3.94 (d, *J* = 0.5 Hz, 2H), 5.75 (d, *J* = 1.3 Hz, 1H), 7.29–7.34 (m, 3H), 7.43–7.46 (m, 2H); ^{13}C NMR (90.6 MHz, $CDCl_3$) δ 16.9, 58.2, 76.5, 86.8, 93.4, 106.5, 123.9, 128.1, 128.4, 131.5, 147.9. MS (70 eV) *m*/*z* (%): 186 (32) [M^+], 171 (100), 128 (52), 115 (38). HRMS Calc. for $C_{13}H_{14}O$: 186.1045. Found: 186.1044.

*4.3.12. (E)-(5-Isopropoxy-4-methylpent-3-en-1-ynyl)benzene (**33**)*

^{1}H NMR (250 MHz, $CDCl_3$) δ 1.18 (d, *J* = 6.0 Hz, 6H), 1.97 (s, 3H), 3.56–3.66 (m, 1H), 3.98 (d, *J* = 0.8 Hz, 2H), 5.78 (d, *J* = 1.3 Hz, 1H), 7.29–7.32 (m, 3H), 7.42–7.46 (m, 2H); ^{13}C NMR (90.6 MHz, $CDCl_3$) δ 17.0, 22.2, 71.2, 71.9, 87.1, 93.2, 105.8. 124.0, 128.0, 128.4, 131.5, 148.8. MS (70 eV) *m*/*z* (%): 214 (32) [M^+], 199 (15), 172 (38), 157 (58), 128 (100). HRMS Calc. for $C_{15}H_{18}O$: 214.1358. Found: 214.1359.

*4.3.13. (Z/E)-1-(5-Methoxy-3-methylpent-3-en-1-ynyl)benzene (**34**)*

^{1}H NMR ($CDCl_3$, 360 MHz) δ 1.93 (s, 0.2H *E*-isomer), 1.99 (s, 1H *Z*-isomer), 3.37 (s, 3H *Z*-isomer, 0.6H *E*-isomer), 4.06 (d, *J* = 6.6 Hz, 0.8H *E*-isomer), 4.21 (d, *J* = 6.8 Hz, 2H *Z*-isomer), 5.84–5.88 (m, 1H *Z*-isomer), 6.02–6.09 (m, 0.2H *E*-isomer), 7.31–7.33 (m, 3H *Z*-isomer, 0.6H *E*-isomer), 7.43–7.46 (m, 2H *Z*-isomer, 0.4H *E*-isomer); ^{13}C NMR (*Z*-isomer, $CDCl_3$, 90 MHz) δ 23.3, 58.2, 71.0, 87.8, 94.3, 121.9, 128.4, 128.4, 128.5, 131.6, 133.5; MS (70 eV) *m*/*z* (%): 186 (3) [M^+], 171 (20), 158 (20), 142 (100), 128 (67), 115 (30).

*4.3.14. (Z/E)-1-(5-Isopropoxy-3-methylpent-3-en-1-ynyl)benzene (**35**)*

^{1}H NMR ($CDCl_3$, 360 MHz) δ 1.19 (d, *J* = 6.1 Hz, 6H *Z*-isomer, 2H *E*-isomer), 1.92 (m, 0.6H *E*-isomer), 1.97 (d, *J* = 1.1 Hz, 3H *Z*-isomer), 3.65–3.69 (m, 1H *Z*-isomer, 0.2H *E*-isomer), 4.09 (dd, *J* = 0.6 Hz, *J* = 6.8 Hz, 0.4H *E*-isomer), 4.25 (dd, *J* = 1.1 Hz, *J* = 6.8 Hz, 2H *Z*-isomer), 5.85–5.89 (m, 1H *Z*-isomer), 6.00–6.10 (m, 0.2H, *E*-isomer), 7.28–7.34 (m, 3H *Z*-isomer, 0.6H *E*-isomer), 7.41–7.45 (m, 2H *Z*-isomer, 0.4H *E*-isomer); ^{13}C NMR (*Z*-isomer, $CDCl_3$, 90 MHz) δ 22.3, 23.3, 66.6, 70.9, 87.9, 94.1, 121.1, 123.5, 128.4, 128.5, 131.6, 134.5; MS (70 eV) *m*/*z* (%): 213 (1), 207 (10), 187 (30), 145 (100), 129 (28), 115 (15).

*4.3.15. (E)-4-Methyl-N-(2-methyl-5-phenylpent-2-en-4-ynyl)benzenesulfonamide (**36**)*

^{1}H NMR (360 MHz, $CDCl_3$) δ 1.90 (s, 3H), 2.43 (s, 3H), 3.62 (d, *J* = 6.4 Hz, 2H), 4.45 (s, br, 1H), 5.63–5.64 (m, 1H), 7.28–7.34 (m, 5H), 7.38–7.44 (m, 2H), 7.75–7.77 (m, 2H); ^{13}C NMR (90.6 MHz, $CDCl_3$) δ 17.6, 21.7, 49.7, 86.2, 94.1, 108.1, 123.5, 127.3, 128.3, 128.5, 129.9, 131.5, 137.1, 143.8, 145.6; MS (70 eV): *m*/*z* (%):348 (100) [M^++Na], 333 (29), 305 (9), 193 (10), 139 (25). HRMS Calc. for $C_{19}H_{19}N$ (M^+−64): 261.1518. Found: 261.1517.

*4.3.16. (Z)-2-(3-Methyl-5-phenylpent-2-en-4-ynyl)furan (**37**)*

^{1}H NMR ($CDCl_3$, 360 MHz) *δ1.96–2.00* (m, 3H *Z*-isomer, 1H *E*-isomer), 3.49 (d, *J* = 7.3 Hz, 0.6H *E*-isomer), 3.69 (d, *J* = 7.3 Hz, 2H *Z*-isomer), 5.87 (qt, *J* = 1.6 Hz, 7.3 Hz, 1H *Z*-isomer), 6.04–6.05 (m, 1H *Z*-isomer), 6.08–6.13 (m, 0.3H *E*-isomer), 6.30 (dd, *J* = 2.0 Hz, 3.2 Hz, 1H, *Z*-isomer), 7.29–7.35 (m, 2H *Z*-isomer, 0.6H *E*-isomer), 7.42–7.47 (m, 3H, *Z*-isomer, 1H *E*-isomer); ^{13}C NMR (*Z*-isomer, $CDCl_3$, 90.6 MHz) δ 23.2, 29.9, 88.3, 93.8, 105.4, 110.4, 120.3, 123.6, 128.3, 128.4, 131.7, 132.5, 141.3, 154.1; MS (70 eV) *m*/*z* (%): 222 (30) [M^+], 207 (100) [M^+-CH_3], 178 (100).

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Appendix A. Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jorganchem.2008.09.062.

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