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$SnCl_2$-Catalyzed Propargylic Substitution of Propargylic Alcohols with Carbon and Nitrogen Nucleophiles

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A weak Lewis acid, tin(II) chloride, which is insensitive to water and air, functioned as a catalyst for the propargylic substitution of secondary propargylic alcohols with carbon nucleophiles, such as electron-rich arenes, heteroarenes, and 1,3-dicarbonyl compounds, and nitrogen nucleophiles, such as sulfonamides, carbamates, and carboxamides, at 40–80 °C in CH_3NO_2 under air and exhibited a higher catalytic activity than tin(II) bromide or iodide in the propargylic substitution of 1-phenyl-2-propyn-1-ol with anisole at 40 °C in CH_3NO_2. The solubility of tin(II) fluoride in CH_3NO_2 would have to be extremely low to cause no propargylic substitution. 1-Phenyl-substituted propargylic alcohols readily reacted with all these nucleophiles, whereas 1-(4-cyanophenyl)-2-propyn-1-ol and 1-(pentafluorophenyl)-2-propyn-1-ol did not react at all with 1,2,3-trimethoxybenzene even in CH_3NO_2 at reflux. The 1-alkyl-substituted secondary propargylic alcohol, 1,5-diphenyl-1-pentyn-3-ol, underwent $SnCl_2$-catalyzed propargylic substitution with electron-rich arenes and amides, although the reaction was slow even at 80 °C in CH_3NO_2. Thus, the $SnCl_2$-catalyzed propargylic substitution reaction is dependent upon the stability of the propargylic carbenium ion formed upon elimination of hydroxide from the corresponding propargylic alcohol.

Introduction

The construction of carbon skeletons bearing alkynes has made considerable progress since the discovery of transition-metal-catalyzed nucleophilic addition to alkynes and cyclization reactions involving alkynes, which have been recognized as methodologies with high potential because of their easy manipulation.[1,2] Thus, simple methods for introducing alkyne moieties into compounds are needed.[3–5] Catalytic propargylic substitution reactions will be useful for incorporating alkyne moieties into various functional compounds such as arenes, heteroarenes, alkenes, 1,3-dicarbonyl compounds, amides, amines, sulfides, and ethers.[6] The propargylic substitution of propargyl alcohols, catalyzed by transition-metal complexes,[7–9] homogeneous[10–23] and heterogeneous[24] Lewis acids, or *p*-toluenesulfonic acid monohydrate,[25] is superior to the propargylic substitution of propargyl esters or halides owing to the availability of the starting propargyl compounds and the release of enrironmentally unbiently leady groups. Above all, Lewis-acid-catalyzed propargylic substitution reactions would attract attention for their ease-of-handling and the availability of nucleophiles. Tin(II) chloride, which is inexpensive and insensitive to water and air, has been used as a Lewis acid catalyst in various organic syntheses.[26] We have also found that tin(II) chloride leads to the elimination of hydroxide from 2-propen-1-ol in cooperation with palladium(0),[27] rhodium(I),[28] or iridium(I)[29] complexes to which alkenes coordinate. Herein we report that tin(II) chloride can be used alone for the propargylic substitution of secondary propargylic alcohols with carbon nucleophiles, such as electron-rich arenes, heteroarenes, and 1,3-dicarbonyl compounds, and nitrogen nucleophiles, such as sulfonamides, carbamates, and carboxamides.

Results and Discussion

The efficiencies of tin(II) halides and solvents in the propargylic substitution of propargylic alcohol were initially investigated by using 1-phenyl-2-propyn-1-ol (**1a**) as the propargylic alcohol and anisole (**2a**) as the carbon nucleophile [Equation (1), Table 1]. The propargylic substitution reaction with tin(II) chloride proceeded at 40 °C for 6 h in CH_3NO_2 to afford a mixture of 3-(2-methoxyphenyl)-3-phenylpropyne (**3aa***o*) and 3-(4-methoxyphenyl)-3-phenylpropyne (**3aa***p*) in 69% yield (entry 2). No propargylic substitution of **1a** with **2a** occurred in the absence of tin(II) chloride in CH_3NO_2. In addition, tin(II) chloride exhibited a higher catalytic activity in CH_3NO_2 than tin(II) bromide or tin(II) iodide (entries 2–4). Propargylic substitution did not occur with tin(II) fluoride because of the extremely low solubility of tin(II) fluoride in CH_3NO_2 (entry 1). Nitromethane was superior to other solvents such as 1,2-dichloroethane, toluene, and acetonitrile (entries 2 and 5–7),

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with no reaction occurring in either THF or DMF. The $SnCl_2$-catalyzed reaction of **1a** with **2a** was accelerated by raising the reaction temperature, but the amounts of structurally undetermined byproducts increased to lower the yields of **3aa** (60 °C, 0.5 h, 59%; 80 °C, 0.5 h, 43%). No allenylation of **2a** with **1a** occurred under any reaction conditions.

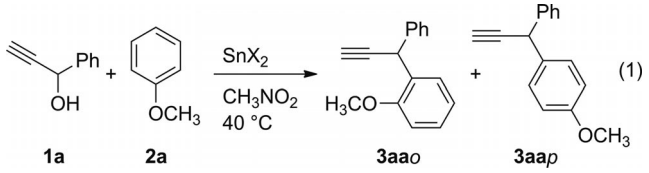


Table 1. Efficiencies of tin(II) halides and solvents in the propargylic substitution of **1a** with **2a**.[a]

Entry	SnX_2	Solvent	Time [h]	Yield of **3aa** [%][b]	Ratio[c] **3aa***o*/**3aa***p*
1	SnF_2	CH_3NO_2	24	0	–
2	$SnCl_2$	CH_3NO_2	6	69	19:81
3	$SnBr_2$	CH_3NO_2	6	54	19:81
4	SnI_2	CH_3NO_2	24	28	20:80
5	$SnCl_2$	$ClCH_2CH_2Cl$	24	49	22:78
6	$SnCl_2$	CH_3CN	24	41	21:79
7	$SnCl_2$	toluene	24	41	24:76

[a] The propargylic substitution of **1a** (0.5 mmol) with **2a** (1.0 mmol) was carried out with SnX_2 (0.1 mmol) at 40 °C in solvent (0.5 mL). The reactions were discontinued after the specified time. [b] Isolated yields. [c] The ratios were determined by ^1H NMR spectroscopy.

Some propargylic alcohols, such as **1a**, 1,3-diphenyl-2-propyn-1-ol (**1b**), 1-(4-chlorophenyl)-3-phenyl-2-propyn-1-ol (**1c**), 1-phenyl-2-nonyn-1-ol (**1d**), and 1,5-diphenyl-1-pentyn-3-ol (**1e**), were used in $SnCl_2$-catalyzed propargylic substitution reactions with electron-rich arenes, such as **2a**, 1,2,3-trimethoxybenzene (**2b**), and 2,6-di-*tert*-butylphenol (**2c**), and heteroarenes, such as pyrrole (**2d**), indole (**2e**), 2-methylfuran (**2f**), and 2-methylthiophene (**2g**), in CH_3NO_2 [Equation (2), Table 2]. The $SnCl_2$-catalyzed reaction of 1-aryl-substituted 2-yn-1-ols (**1b–d**) bearing an internal alkyne with arenes **2** as described above proceeded readily at 40 °C for 10 min in CH_3NO_2 to produce the corresponding propargylated arenes **3** regioselectively in moderate-to-high isolated yields (entries 3–15). The propargylic substitution of **1b–d** with **2a** only produced the corresponding *para* products (entries 3, 9, and 12) in contrast to that of **1a**, which yielded both *ortho* and *para* products. To the best of our knowledge, no propargylic substitution of 1-alkyl-substituted secondary propargylic alcohols with carbon nu-

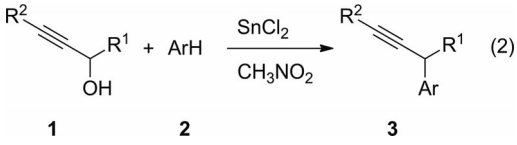


Table 2. $SnCl_2$-catalyzed propargylic substitution of propargylic alcohols **1** with arenes **2**.[a]

Entry	**1**	**2**	*T* [°C]	*t* [min]	**3**	Yield [%][b]
1	**1a** (R^1 = Ph, R^2 = H)	**2b**	40	6 h	**3ab**	30
2	**1a** (R^1 = Ph, R^2 = H)	**2c**	40	6 h	**3ac**	75
3	**1b** (R^1 = Ph, R^2 = Ph)	**2a**	40	10	**3ba**	77
4	**1b** (R^1 = Ph, R^2 = Ph)	**2b**	40	10	**3bb**	89
5	**1b** (R^1 = Ph, R^2 = Ph)	**2d**	40	10	**3bd**	83
6	**1b** (R^1 = Ph, R^2 = Ph)	**2e**	40	10	**3be**	95
7	**1b** (R^1 = Ph, R^2 = Ph)	**2f**	40	10	**3bf**	80
8	**1b** (R^1 = Ph, R^2 = Ph)	**2g**	40	10	**3bg**	80
9	**1c** (R^1 = 4-ClC_6H_4, R^2 = Ph)	**2a**	40	10	**3ca**	78
10	**1c** (R^1 = 4-ClC_6H_4, R^2 = Ph)	**2c**	40	10	**3cc**	98

Table 2. (*Continued*)

Entry	1	2	T [°C]	t [min]	3	Yield [%][b]
11	**1c** (R^1 = 4-ClC_6H_4, R^2 = Ph)	**2g**	40	10	**3cg**	74
12	**1d** (R^1 = Ph, R^2 = C_6H_{13})	**2a**	40	10	**3da**	77
13	**1d** (R^1 = Ph, R^2 = C_6H_{13})	**2b**	40	10	**3db**	88
14	**1d** (R^1 = Ph, R^2 = C_6H_{13})	**2c**	40	10	**3dc**	80
15	**1d** (R^1 = Ph, R^2 = C_6H_{13})	**2d**	40	10	**3dd**	47
16	**1e** (R^1 = $Ph(CH_2)_2$, R^2 = Ph)	**2b**	80	21 h	**3eb**	51
17	**1e** (R^1 = $Ph(CH_2)_2$, R^2 = Ph)	**2c**	80	4 h	**3ec**	67

[a] The propargylic substitution of **1** (0.5 mmol) with **2** (1.0 mmol) was carried out with $SnCl_2$ (0.1 mmol) in CH_3NO_2 (0.5 mL). [b] Isolated yields.

cleophiles has occurred with simple Lewis acids,[21] whereas tin(II) chloride can be used as a catalyst in the propargylic substitution of **1e** with electron-rich arenes such as **2b** and **2c**, although **1e** is less reactive than **1b**–**d**; the reaction of **1e** needs a high reaction temperature (80 °C; entries 16 and 17). Neither 1-(4-cyanophenyl)-2-propyn-1-ol (**1f**) nor 1-(pentafluorophenyl)-2-propyn-1-ol (**1g**) reacted with **2b** in the presence of tin(II) chloride (20 mol-%) even in CH_3NO_2 at reflux. Thus, 1-aryl substituents bearing electron-withdrawing groups, namely 4-cyanophenyl and pentafluorophenyl, inhibit the propargylic substitution reactions, which suggests that the $SnCl_2$-catalyzed propargylic substitution is an S_N1 reaction that occurs via the formation of propargylic carbenium ions by the elimination of hydroxide from the corresponding propargylic alcohols, similarly to previously reported Lewis acid catalyzed propargylic substitution reactions.[10–24] A plausible mechanism is illustrated in Figure 1. First, the hydroxy group of propargylic alcohol **1** probably coordinates to tin(II) to form complex **A**, from which the hydroxy group can be eliminated as dichlorohydroxystannate **B** to generate propargylic carbenium ion **C**. Next, an electron-rich arene such as **2a** attacks **C** to form a σ complex **D**, from which a proton can be abstracted by **B** to form the propargylated product **3** and water with regeneration of the catalyst $SnCl_2$. In the cases of R^1 = 4-cyanophenyl or pentafluorophenyl, the corresponding carbenium ion **C** is hard to prepare because electron-withdrawing groups such as cyano and fluoro destabilize the carbenium ion.

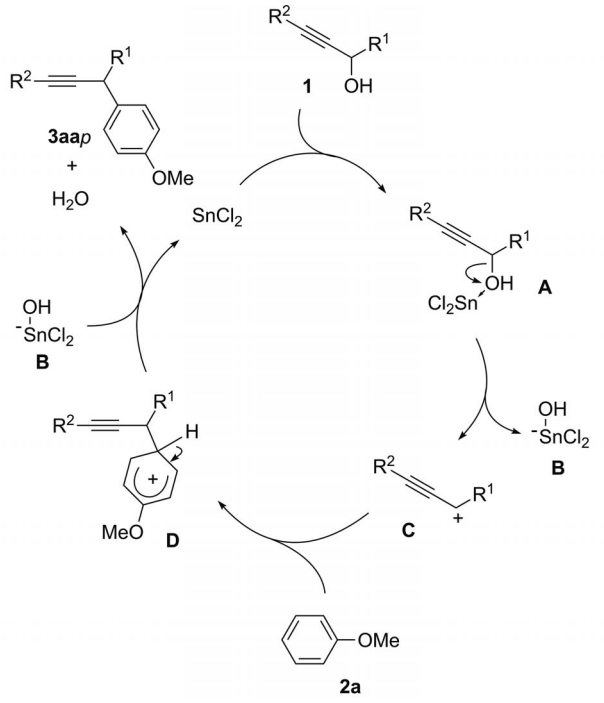


Figure 1. Plausible mechanism for the $SnCl_2$-catalyzed propargylic substitution reaction.

1,3-Dicarbonyl compounds, such as 2,4-pentanedione (**4a**), 1,3-diphenyl-1,3-propanedione (**4b**), and ethyl acetoacetate (**4c**), were also used in the $SnCl_2$-catalyzed propargylic substitution of 1-phenyl-2-propyn-1-ols **1a**, **1b**, and **1d** at 40 °C in CH_3NO_2 to prepare the corresponding 2-propargyl-1,3-dicarbonyl compounds **5** [Equation (3)]. The results are summarized in Table 3. 1,3-Dicarbonyl compounds **4a**–**c** selectively underwent monopropargylation with propargylic alcohols **1a**, **1b**, and **1d**. 1,3-Diketones **4a** and **4b** were more reactive than keto ester **4c** in the propargylic substitution of **1b** (entries 2–4) and propargylic alcohols **1b** and **1d** with an internal alkyne were more reactive than **1a** with a terminal alkyne in the reaction with **4b** (entries 1, 3, and 6). 1-Alkyl-substituted propargylic alcohol **1e** did not react with **4b** at 80 °C in CH_3NO_2 at all.

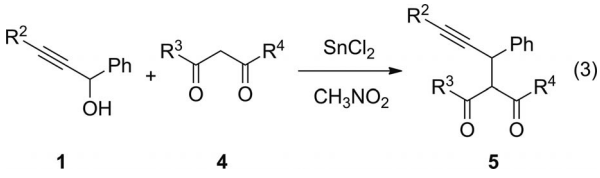
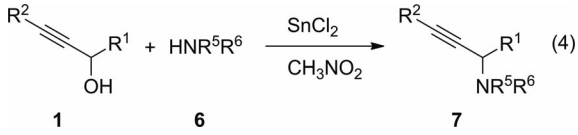


Table 3. Propargylic substitution of 1-phenyl-2-propyn-1-ols **1a**, **1b**, and **1d** with 1,3-dicarbonyl compounds **4**.[a]

Entry	1	4	Time [min]	5, Yield [%][b]
1	**1a** (R^2 = H)	**4b** (R^3, R^4 = Ph)	120	**5ab**, 78
2	**1b** (R^2 = Ph)	**4a** (R^3, R^4 = Me)	10	**5ba**, 81
3	**1b** (R^2 = Ph)	**4b** (R^3, R^4 = Ph)	10	**5bb**, 75
4	**1b** (R^2 = Ph)	**4c** (R^3 = Me, R^4 = OEt)	45	**5bc**, 64[c]
5	**1d** (R^2 = C_6H_{13})	**4a** (R^3, R^4 = Me)	10	**5da**, 88
6	**1d** (R^2 = C_6H_{13})	**4b** (R^3, R^4 = Ph)	10	**5db**, 88

[a] The propargylic substitution of **1** (0.5 mmol) with **4** (1.0 mmol) was carried out with $SnCl_2$ (0.1 mmol) at 40 °C in CH_3NO_2 (0.5 mL). The reactions were discontinued after the specified time. [b] Isolated yields. [c] The diastereomeric ratio determined by ^1H NMR spectroscopy was ca. 55:45.

The $SnCl_2$-catalyzed propargylic substitutions of **1a**, **1b**, **1d**, or **1e** with nitrogen nucleophiles, namely amides such as benzenesulfonamide (**6a**), *p*-toluenesulfonamide (**6b**), *N*-methyl-*p*-toluenesulfonamide (**6c**), ethyl carbamate (**6d**), benzyl carbamate (**6e**), ethyl *N*-methylcarbamate (**6f**), and benzamide (**6g**), were investigated in CH_3NO_2 as solvent [Equation (4)]. The results are summarized in Table 4. Amides **6a**, **6b**, **6d**, **6e**, and **6g** selectively underwent *N*-monopropargylation with all the propargylic alcohols tested (entries 1, 2, 4, 5, 7–9, 11, 13, and 14). The most reactive propargylic alcohols were, in the following order, **1b**, **1d**, **1a**, and **1e** for the propargylation of amides **6b** and **6c** with tin(II) chloride in CH_3NO_2 (entries 2, 3, 5, 6, 9, 10, 14, and 15).



Conclusions

A weak Lewis acid, tin(II) chloride, has been used as catalyst in the propargylic substitution of secondary propargylic alcohols **1** with electron-rich arenes, heteroarenes, 1,3-dicarbonyl compounds, and amides, which has the following advantages in synthetic methodology: i. The inexpensiveness of tin(II) chloride, ii. the insensitiveness of ti-

Table 4. Propargylic substitution of propargyl alcohols with amides **6**.[a]

Entry	1	Amide 6	$SnCl_2$ [mmol]	Temp. [°C]	Time [h]	7, Yield [%][b]
1	**1a** (R^1 = Ph, R^2 = H)	**6a** (R^5 = H, R^6 = SO_2Ph)	0.1	40	24	**7aa**, 38
2	**1a** (R^1 = Ph, R^2 = H)	**6b** (R^5 = H, R^6 = SO_2pTol)	0.1	40	24	**7ab**, 47
3	**1a** (R^1 = Ph, R^2 = H)	**6c** (R^5 = Me, R^6 = SO_2pTol)	0.1	40	24	**7ac**, 90
4	**1a** (R^1 = Ph, R^2 = H)	**6d** (R^5 = H, R^6 = COOEt)	0.25	80	24	**7ad**, 71
5	**1b** (R^1 = Ph, R^2 = Ph)	**6b** (R^5 = H, R^6 = SO_2pTol)	0.1	40	3	**7bb**, 69
6	**1b** (R^1 = Ph, R^2 = Ph)	**6c** (R^5 = Me, R^6 = SO_2pTol)	0.1	40	3	**7bc**, 90
7	**1b** (R^1 = Ph, R^2 = Ph)	**6e** (R^5 = H, R^6 = $COOCH_2Ph$)	0.1	80	3	**7be**, 83
8	**1b** (R^1 = Ph, R^2 = Ph)	**6g** (R^5 = H, R^6 = COPh)	0.1	80	3	**7bg**, 61
9	**1d** (R^1 = Ph, R^2 = C_6H_{13})	**6b** (R^5 = H, R^6 = SO_2pTol)	0.1	40	3	**7db**, 69
10	**1d** (R^1 = Ph, R^2 = C_6H_{13})	**6c** (R^5 = Me, R^6 = SO_2pTol)	0.1	40	3	**7dc**, 84
11	**1d** (R^1 = Ph, R^2 = C_6H_{13})	**6d** (R^5 = H, R^6 = COOEt)	0.1	80	3	**7dd**, 88
12	**1d** (R^1 = Ph, R^2 = C_6H_{13})	**6f** (R^5 = Me, R^6 = COOEt)	0.1	80	6	**7df**, 80
13	**1e** (R^1 = $PhCH_2CH_2$, R^2 = Ph)	**6a** (R^5 = H, R^6 = SO_2Ph)	0.25	80	24	**7ea**, 34
14	**1e** (R^1 = $PhCH_2CH_2$, R^2 = Ph)	**6b** (R^5 = H, R^6 = SO_2pTol)	0.25	80	24	**7eb**, 42
15	**1e** (R^1 = $PhCH_2CH_2$, R^2 = Ph)	**6c** (R^5 = Me, R^6 = SO_2pTol)	0.1	80	24	**7ec**, 51

[a] The propargylic substitution of **1** (0.5 mmol) with **6** (1.0 mmol) was carried out with $SnCl_2$ in CH_3NO_2 (0.5 mL). The reactions were discontinued after the specified time. [b] Isolated yields.

n(II) chloride to water and air, and iii. the ease of handling. The $SnCl_2$-catalyzed propargylic substitution of **1** is dependent upon the stability of the propargylic carbenium ions, formed by the elimination of hydroxide from the corresponding propargylic alcohols, because the reactivity of the propargylic alcohols decreases in the order **1b** > **1d** > **1a** > **1e** and, furthermore, propargylic substitution did not occur with 1-(4-cyanophenyl)-2-propyn-1-ol and 1-(pentafluorophenyl)-2-propyn-1-ol.

Experimental Section

General Methods: 1-Phenyl-2-propyn-1-ol (**1a**) was purchased from Wako Pure Chemical Industries, Ltd. 1,3-Diphenyl-2-propyn-1-ol (**1b**), 1-(4-chlorophenyl)-3-phenyl-2-propyn-1-ol (**1c**), 1-phenyl-2-nonyn-1-ol (**1d**), and 1,5-diphenyl-1-pentyn-3-ol (**1e**) were prepared from terminal alkynes and aldehydes according to the literature procedure.[30] Anisole (**2a**), 2-methylthiophene (**2g**) and 1,3-diphenyl-1,3-propanedione (**4b**) were purchased from Sigma–Aldrich Co. 1,2,3-Trimethoxybenzene (**2b**), 2,6-di-*tert*-butylphenol (**2c**), indole (**2e**), 2-methylfuran (**2f**), ethyl acetoacetate (**4c**), benzenesulfonamide (**6a**), *p*-toluenesulfonamide (**6b**), *N*-methyl-*p*-toluenesulfonamide (**6c**), ethyl carbamate (**6d**), benzyl carbamate (**6e**), ethyl *N*-methylcarbamate (**6f**), and benzamide (**6g**) were purchased from Tokyo Chemical Industry Co., Ltd. Pyrrole (**2d**) and 2,4-pentanedione (**4a**) were purchased from Kanto Chemical Co. All purchased reagents were used as received. Tin(II) chloride (Wako first-grade, over 97%) was purchased from Wako Pure Chemical Industries, Ltd. and used after being dried at 120 °C for 5 h under vacuum.

TLC analyses were carried out on silica gel plates (Merck Art.5735) and column chromatography was carried out on silica gel (Kanto Chemical Co., Inc. Cat. No.37564). HPLC purification was carried out with a Japan Analysis Industry LC-908 or LC-9201 (JAIGEL-2 H, $CHCl_3$) instrument. NMR spectra were recorded with a JEOL JMS-LA300 or JMS-LA500 spectrometer. IR spectra were recorded with a Shimadzu FTIR-8300 spectrometer. EI-MS spectra were recorded with a JEOL JMS-700 spectrometer. Elemental analyses were carried out with a Perkin–Elmer PE2400 Series II CHNS/O Analyzer instrument.

Typical Procedure for the $SnCl_2$-Catalyzed Propargylic Substitution of Propargylic Alcohols with Carbon or Nitrogen Nucleophiles: Anisole (**2a**; 0.11 g, 1 mmol) and 1-phenyl-2-propyn-1-ol (**1a**; 66 mg, 0.5 mmol) were added to a solution of tin(II) chloride (19 mg, 0.1 mmol) in CH_3NO_2 (0.5 mL). The solution was stirred at 40 °C for 6 h, monitoring by TLC, and then was extracted with diethyl ether/dichloromethane (1:1; 10 mL). The extracted mixture was washed with water (2 × 30 mL) and brine (30 mL), and then dried with anhydrous $MgSO_4$. After evaporation of the volatiles, purification by column chromatography (silica gel, hexane/EtOAc = 10:1) and HPLC (Japan Analytical Industry, LC-908, JAIGEL-2 H, $CHCl_3$) afforded 77 mg (69%) of a mixture of 3-(2-methoxyphenyl)-3-phenylpropyne (**3aa***o*) and 3-(4-methoxyphenyl)-3-phenylpropyne (**3aa***p*) (**3aa***o*/**3aa***p* = 19:81) as a colorless oil.

1-Methoxy-2-(1-phenyl-2-propynyl)benzene (3aa*o*) and 1-Methoxy-4-(1-phenyl-2-propynyl)benzene (3aa*p*): R_f = 0.58 (hexane/ethyl acetate = 3:1). NMR data for **3aa***o*: ^1H NMR (300 MHz, $CDCl_3$): δ = 2.38 (d, J = 2.7 Hz, 1 H), 3.79 (s, 3 H), 5.49 (d, J = 2.7 Hz, 1 H), 6.82–6.85 (m, 1 H), 6.94 (t, J = 7.5 Hz, 1 H), 7.15–7.42 (m, 6 H), 7.52 (d, J = 7.5 Hz, 1 H) ppm; NMR data for **3aa***p*: ^1H NMR (300 MHz, $CDCl_3$): δ = 2.47 (d, J = 2.7 Hz, 1 H), 3.76 (s, 3 H), 4.96 (d, J = 2.7 Hz, 1 H), 6.83 (d, J = 8.7 Hz, 2 H), 7.28 (d, J = 8.7 Hz, 2 H), 7.15–7.42 (m, 5 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 42.0, 55.2, 72.6, 84.9, 114.0, 126.9, 127.7, 128.6, 128.8, 133.3, 141.4, 158.5 ppm. HRMS (EI): calcd. for $C_{16}H_{14}O$ 222.1045; found 222.1048.

1,2,3-Trimethoxy-4-(1-phenyl-2-propynyl)benzene (3ab): R_f = 0.43 (hexane/ethyl acetate = 3:1). ^1H NMR (500 MHz, $CDCl_3$): δ = 2.41 (d, J = 2.5 Hz, 1 H), 3.74 (s, 3 H), 3.84 (s, 3 H), 3.85 (s, 3 H), 5.35 (d, J = 2.5 Hz, 1 H), 6.66 (d, J = 8.5 Hz, 1 H), 7.15 (d, J = 8.5 Hz, 1 H), 7.20 (t, J = 7.5 Hz, 1 H), 7.29 (t, J = 7.5 Hz, 2 H), 7.38 (d, J = 7.5 Hz, 2 H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 36.2, 56.0, 60.7, 60.8, 71.8, 85.2, 107.3, 123.1, 126.7, 127.4, 127.7, 128.4, 141.4, 142.1, 150.9, 153.0 ppm. HRMS (EI): calcd. for $C_{18}H_{18}O_3$ 282.1256; found 282.1264.

2,6-Di-*tert*-butyl-4-(1-phenyl-2-propynyl)phenol (3ac): R_f = 0.67 (hexane/ethyl acetate = 3:1). ^1H NMR (300 MHz, $CDCl_3$): δ = 1.40 (s, 18 H), 2.45 (d, J = 2.7 Hz, 1 H), 4.93 (d, J = 2.7 Hz, 1 H), 5.11 (s, 1 H), 7.17 (s, 2 H), 7.22 (d, J = 7.2 Hz, 1 H), 7.30 (t, J = 7.2 Hz, 1 H), 7.39 (d, J = 7.2 Hz, 1 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 30.2, 34.4, 42.8, 72.2, 85.5, 124.5, 126.7, 127.7, 128.5, 131.5, 135.9, 141.7, 152.7 ppm. HRMS (EI): calcd. for $C_{23}H_{28}O$ 320.2140; found 320.2139.

1-(1,3-Diphenyl-2-propynyl)-4-methoxybenzene (3ba): R_f = 0.61 (hexane/ethyl acetate = 3:1). ^1H NMR (300 MHz, $CDCl_3$): δ = 3.74 (s, 3 H), 5.15 (s, 1 H), 6.84 (d, J = 8.7 Hz, 2 H), 7.17–7.36 (m, 8 H), 7.40–7.49 (m, 4 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 42.9, 55.2, 84.7, 90.5, 113.9, 123.5, 126.8, 127.8, 127.9, 128.2, 128.6, 128.9, 131.6, 133.9, 142.0, 158.5 ppm. HRMS (EI): calcd. for $C_{22}H_{18}O$ 298.1358; found 298.1355.

1-(1,3-Diphenyl-2-propynyl)-2,3,4-trimethoxybenzene (3bb): R_f = 0.63 (hexane/ethyl acetate = 3:1). ^1H NMR (300 MHz, $CDCl_3$): δ = 3.78 (s, 3 H), 3.80 (s, 3 H), 3.85 (s, 3 H), 5.56 (s, 1 H), 6.64 (d, J = 8.7 Hz, 1 H), 7.14–7.31 (m, 7 H), 7.40–7.50 (m, 4 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 37.0, 55.9, 60.6, 60.8, 83.8, 90.8, 107.2, 123.1, 123.6, 126.5, 127.8, 127.9, 128.1, 128.3, 129.6, 131.6, 141.9, 142.0, 150.9, 152.8 ppm. HRMS (EI): calcd. for $C_{24}H_{22}O_3$ 358.1569; found 358.1571.

2-(1,3-Diphenyl-2-propynyl)pyrrole (3bd):[13] R_f = 0.50 (hexane/ethyl acetate = 3:1). ^1H NMR (300 MHz, $CDCl_3$): δ = 5.27 (s, 1 H), 6.02–6.06 (m, 1 H), 6.15 (dd, J = 5.4, 2.7 Hz, 1 H), 6.66–6.70 (m, 1 H), 7.23–7.36 (m, 6 H), 7.43–7.49 (m, 4 H), 8.13 (br., 1 H) ppm.

3-(1,3-Diphenyl-2-propynyl)indole (3be):[15] R_f = 0.37 (hexane/ethyl acetate = 3:1). ^1H NMR (300 MHz, $CDCl_3$): δ = 5.45 (s, 1 H), 7.00–7.62 (m, 15 H), 7.88 (br., 1 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 35.4, 83.3, 90.5, 111.2, 116.8, 119.6, 122.2, 122.6, 123.6, 126.0, 126.7, 127.8, 127.9, 128.2, 128.5, 131.6, 131.7, 136.6, 141.2 ppm.

2-(1,3-Diphenyl-2-propynyl)-5-methylfuran (3bf):[7c] R_f = 0.67 (hexane/ethyl acetate = 3:1). ^1H NMR (300 MHz, $CDCl_3$): δ = 2.24 (s, 3 H), 5.20 (s, 1 H), 5.89 (d, J = 3.0 Hz, 1 H), 6.12 (d, J = 3.0 Hz, 1 H), 7.24–7.39 (m, 6 H), 7.46–7.51 (m, 4 H) ppm.

2-(1,3-Diphenyl-2-propynyl)-5-methylthiophene (3bg): R_f = 0.67 (hexane/ethyl acetate = 3:1). ^1H NMR (300 MHz, $CDCl_3$): δ = 2.38 (s, 3 H), 5.32 (s, 1 H), 6.54 (d, J = 3.3 Hz, 1 H), 6.76 (d, J = 3.3 Hz, 1 H), 7.23–7.35 (m, 6 H), 7.42–7.49 (m, 4 H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 15.3, 39.3, 84.2, 89.5, 123.2, 124.6, 124.7, 127.5, 127.6, 128.1, 128.2, 128.6, 131.7, 139.4, 141.3, 143.2 ppm. HRMS (EI): calcd. for $C_{20}H_{16}S$ 288.0973; found 288.0967.

1-[1-(4-Chlorophenyl)-3-phenyl-2-propynyl]-4-methoxybenzene (3ca):[21a] R_f = 0.61 (hexane/ethyl acetate = 3:1). ^1H NMR (300 MHz, $CDCl_3$): δ = 3.75 (s, 3 H), 5.11 (s, 1 H), 6.85 (d, J = 8.4 Hz, 2 H), 7.25–7.35 (m, 9 H), 7.41–7.47 (m, 2 H) ppm. ^{13}C

NMR (75 MHz, $CDCl_3$): δ = 42.3, 55.2, 85.0, 89.9, 114.0, 123.2, 128.1, 128.2, 128.6, 128.8, 129.1, 131.6, 132.6, 133.4, 140.6, 158.6 ppm.

2,6-Di-*tert*-butyl-4-[1-(4-chlorophenyl)-3-phenyl-2-propynyl]phenol (3cc): R_f = 0.73 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.42 (s, 18 H), 5.09 (s, 1 H), 5.14 (s, 1 H), 7.23 (s, 2 H), 7.25–7.32 (m, 5 H), 7.37 (d, J = 8.1 Hz, 2 H), 7.42–7.47 (m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 30.2, 34.4, 43.0, 84.8, 90.5, 123.5, 124.4, 127.9, 128.2, 128.6, 129.2, 131.5, 131.6, 132.4, 136.0, 140.9, 152.8 ppm. HRMS (EI): calcd. for $C_{29}H_{31}{}^{35}ClO$ 430.2063; found 430.2058.

2-[1-(4-Chlorophenyl)-3-phenyl-2-propynyl]-5-methylthiophene (3cg): R_f = 0.73 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.39 (s, 3 H), 5.29 (s, 1 H), 6.55 (d, J = 3.6 Hz, 1 H), 6.75 (d, J = 3.6 Hz, 1 H), 7.27–7.31 (m, 3 H), 7.30 (d, J = 8.7 Hz, 2 H), 7.39 (d, J = 8.7 Hz, 2 H), 7.42–7.49 (m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 15.3, 38.6, 84.6, 88.9, 123.0, 124.6, 124.9, 128.2, 128.6, 128.8, 129.0, 131.7, 133.1, 139.6, 139.8, 142.5 ppm. HRMS (EI): calcd. for $C_{20}H_{15}{}^{35}ClS$ 322.0583; found 322.0588.

1-Methoxy-4-(1-phenyl-2-nonynyl)benzene (3da): R_f = 0.70 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.88 (t, J = 6.9 Hz, 3 H), 1.24–1.60 (m, 8 H), 2.26 (td, J = 6.9, 2.4 Hz, 2 H), 3.74 (s, 3 H), 4.91 (t, J = 2.4 Hz, 1 H), 6.81 (d, J = 9.0 Hz, 2 H), 7.15–7.37 (m, 7 H) ppm. HRMS (EI): calcd. for $C_{22}H_{26}O$ 306.1984; found 306.1987.

1,2,3-Trimethoxy-4-(1-phenyl-2-nonynyl)benzene (3db): R_f = 0.60 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.88 (t, J = 6.9 Hz, 3 H), 1.24–1.59 (m, 8 H), 2.24 (td, J = 7.2, 2.4 Hz, 2 H), 3.73 (s, 3 H), 3.80 (s, 3 H), 3.83 (s, 3 H), 5.31 (t, J = 2.4 Hz, 1 H), 6.63 (d, J = 8.7 Hz, 1 H), 7.12–7.28 (m, 4 H), 7.37 (d, J = 7.5 Hz, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 13.9, 18.8, 22.5, 28.5, 28.9, 31.2, 36.3, 55.8, 60.5, 60.6, 81.0, 84.0, 107.1, 123.0, 126.2, 127.6, 128.1, 128.6, 141.9, 142.7, 150.8, 152.5 ppm. HRMS (EI): calcd. for $C_{24}H_{30}O_3$ 366.2195; found 366.2190.

2,6-Di-*tert*-butyl-4-(1-phenyl-2-nonynyl)phenol (3dc): R_f = 0.70 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.88 (t, J = 6.9 Hz, 3 H), 1.25–1.60 (m, 8 H), 1.40 (s, 18 H), 2.27 (td, J = 6.9, 2.1 Hz, 2 H), 4.89 (br., 1 H), 5.06 (s, 1 H), 7.14–7.19 (m, 1 H), 7.19 (s, 2 H), 7.27 (t, J = 7.5 Hz, 2 H), 7.38 (d, J = 7.5 Hz, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.1, 19.0, 22.6, 28.6, 29.0, 30.3, 31.4, 34.4, 43.2, 81.4, 84.6, 124.4, 126.4, 127.7, 128.3, 132.8, 135.6, 143.1, 152.4 ppm. HRMS (EI): calcd. for $C_{29}H_{40}O$ 404.3079; found 404.3092.

2-(1-Phenyl-2-nonynyl)pyrrole (3dd): R_f = 0.73 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.89 (t, J = 6.9 Hz, 3 H), 1.26–1.60 (m, 8 H), 2.26 (dt, J = 7.5, 2.4 Hz, 2 H), 5.02 (br., 1 H), 5.94 (br., 1 H), 6.11 (dd, J = 6.0, 3.0 Hz, 1 H), 6.66 (m, 1 H), 7.20–7.40 (m, 5 H), 8.15 (br., 1 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.0, 18.9, 22.5, 28.6, 28.8, 31.3, 36.7, 79.0, 84.5, 106.0, 108.6, 116.9, 127.0, 127.6, 128.5, 131.4, 140.9 ppm. HRMS (EI): calcd. for $C_{19}H_{23}N$ 265.1830; found 265.1831.

1,2,3-Trimethoxy-4-[1-(2-phenylethyl)-3-phenyl-2-propynyl]benzene (3eb): R_f = 0.55 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.04–2.15 (m, 2 H), 2.76–2.97 (m, 2 H), 3.83 (s, 3 H), 3.85 (s, 3 H), 3.86 (s, 3 H), 4.15 (t, J = 7.2 Hz, 1 H), 6.67 (d, J = 8.7 Hz, 1 H), 7.14–7.34 (m, 9 H), 7.44–7.50 (m, 2 H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 31.4, 33.9, 39.0, 56.0, 60.7, 61.0, 82.8, 91.9, 107.3, 122.6, 123.9, 125.8, 127.7, 127.9, 128.2, 128.3, 128.5, 131.6, 141.8, 142.1, 150.9, 152.6 ppm. HRMS (EI): calcd. for $C_{26}H_{26}O_3$ 386.1882; found 386.1894.

2,6-Di-*tert*-butyl-4-[1-(2-phenylethyl)-3-phenyl-2-propynyl]phenol (3ec): R_f = 0.77 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.45 (s, 18 H), 2.07–2.17 (m, 2 H), 2.76–2.97 (m, 2 H), 3.77 (t, J = 7.3 Hz, 1 H), 5.10 (s, 1 H), 7.16–7.32 (m, 8 H), 7.18 (s, 2 H), 7.44–7.48 (m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 30.3, 33.9, 34.4, 37.8, 40.3, 83.7, 92.0, 124.0, 125.8, 127.6, 128.2, 128.3, 128.5, 131.6, 132.4, 135.8, 141.9, 152.5 ppm. HRMS (EI): calcd. for $C_{31}H_{36}O$ 424.2766; found 424.2785.

2-(1-Phenyl-2-propynyl)-1,3-diphenyl-1,3-propanedione (5ab):[25b] R_f = 0.35 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.18 (d, J = 2.7 Hz, 1 H), 4.96 (dd, J = 9.9, 2.7 Hz, 1 H), 5.83 (d, J = 9.9 Hz, 1 H), 7.10–7.31 (m, 5 H), 7.40–7.47 (m, 5 H), 7.53–7.58 (m, 1 H), 7.69 (d, J = 7.2 Hz, 2 H), 8.01 (d, J = 7.2 Hz, 2 H) ppm.

3-(1,3-Diphenyl-2-propynyl)-2,4-pentanedione (5ba):[25b] R_f = 0.33 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.91 (s, 3 H), 2.37 (s, 3 H), 4.22 (d, J = 10.8 Hz, 1 H), 4.67 (d, J = 10.8 Hz, 1 H), 7.24–7.42 (m, 10 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 28.7, 31.0, 38.0, 75.5, 84.8, 88.0, 122.6, 127.7, 128.1, 128.2, 128.3, 128.8, 131.6, 138.1, 201.4, 201.5 ppm.

2-(1,3-Diphenyl-2-propynyl)-1,3-diphenyl-1,3-propanedione (5bb):[25b] R_f = 0.40 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 5.19 (d, J = 9.9 Hz, 1 H), 5.93 (d, J = 9.9 Hz, 1 H), 6.98–7.03 (m, 2 H), 7.09–7.18 (m, 4 H), 7.21–7.30 (m, 4 H), 7.37–7.49 (m, 3 H), 7.52–7.59 (m, 3 H), 7.75 (d, J = 7.5 Hz, 2 H), 8.12 (d, J = 7.5 Hz, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 38.7, 63.0, 85.0, 89.3, 122.8, 127.4, 127.9, 128.4, 128.5, 128.6, 128.8, 129.0, 131.3, 133.4, 133.5, 136.4, 136.9, 139.2, 192.5, 193.3 ppm. HRMS (EI): calcd. for $C_{30}H_{22}O_2$ 414.1620; found 414.1626.

Ethyl 2-(1,3-Diphenyl-2-propynyl)-3-oxobutanoate (5bc):[25b] A mixture of two diastereomers in a diastereomeric ratio of 55:45. R_f = 0.40 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): isomer 1: δ = 1.03 (t, J = 7.2 Hz, 3 H), 2.41 (s, 3 H), 3.98 (q, J = 7.2 Hz, 2 H), 4.00 (d, J = 10.2 Hz, 1 H), 4.62 (d, J = 10.2 Hz, 1 H), 7.20–7.50 (m, 10 H); isomer 2: δ = 1.27 (t, J = 7.2 Hz, 3 H), 2.00 (s, 3 H), 4.06 (d, J = 10.2 Hz, 1 H), 4.25 (q, J = 7.2 Hz, 2 H), 4.65 (d, J = 10.2 Hz, 1 H), 7.20–7.50 (m, 10 H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 13.7, 14.1, 29.7, 30.5, 37.7, 37.8, 61.5, 61.7, 66.5, 66.7, 84.0, 84.6, 88.1, 88.4, 122.7, 123.0, 127.55, 127.59, 128.0, 128.11, 128.14, 128.16, 128.24, 128.55, 128.65, 131.5, 138.1, 138.2, 166.7, 167.0, 200.2, 200.7 ppm.

3-(1-Phenyl-2-nonynyl)-2,4-pentanedione (5da): R_f = 0.53 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.88 (t, J = 6.6 Hz, 3 H), 1.17–1.50 (m, 8 H), 1.87 (s, 3 H), 2.15 (td, J = 6.9, 2.4 Hz, 2 H), 2.33 (s, 3 H), 4.08 (d, J = 11.1 Hz, 1 H), 4.41 (dt, J = 11.1, 2.4 Hz, 1 H), 7.18–7.35 (m, 5 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.0, 18.6, 22.5, 28.4, 28.6, 31.1, 31.2, 37.7, 76.0, 78.6, 85.4, 127.4, 127.9, 128.7, 138.8, 201.89, 201.92 ppm. HRMS (EI): calcd. for $C_{20}H_{26}O_2$ 298.1933; found 298.1930.

3-(1-Phenyl-2-nonynyl)-1,3-diphenyl-1,3-propanedione (5db): R_f = 0.42 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.83 (t, J = 6.9 Hz, 3 H), 1.05–1.24 (m, 8 H), 1.88–1.96 (m, 2 H), 4.96 (br. d, J = 10.2 Hz, 1 H), 5.84 (dd, J = 10.2, 1.5 Hz, 1 H), 7.06–7.13 (m, 1 H), 7.16–7.26 (m, 4 H), 7.33–7.40 (m, 1 H), 7.41–7.58 (m, 5 H), 7.71 (d, J = 7.8 Hz, 2 H), 8.09 (d, J = 7.8 Hz, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.0, 18.6, 22.4, 28.3, 31.2, 38.3, 63.4, 79.7, 85.5, 127.1, 128.3, 128.4, 128.5, 128.6, 129.0, 133.2, 133.3, 136.5, 137.0, 139.8, 192.7, 193.4 ppm. $C_{30}H_{30}O_2$ (422.57): calcd. C 85.27, H 7.16; found C 84.97, H 6.95.

***N*-(1-Phenyl-2-propynyl)benzenesulfonamide (7aa):** R_f = 0.23 (hexane/ethyl acetate = 3:1). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 2.29 (d,

J = 2.5 Hz, 1 H), 5.04 (d, J = 8.5 Hz, 1 H), 5.35 (dd, J = 8.5, 2.5 Hz, 1 H), 7.27–7.34 (m, 3 H), 7.44–7.51 (m, 4 H), 7.55–7.59 (m, 1 H), 7.89 (d, J = 8.0 Hz, 2 H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 49.0, 74.8, 80.2, 127.2, 127.4, 128.6, 128.7, 128.9, 132.8, 136.7, 140.2 ppm. HRMS (EI): calcd. for $C_{15}H_{13}NO_2S$ 271.0667; found 271.0666.

***N*-(1-Phenyl-2-propynyl)-*p*-toluenesulfonamide (7ab):**[7d] R_f = 0.23 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.31 (d, J = 2.4 Hz, 1 H), 2.42 (s, 3 H), 5.09 (br., 1 H), 5.31 (dd, J = 9.0, 2.4 Hz, 1 H), 7.25–7.35 (m, 5 H), 7.43–7.47 (m, 2 H), 7.76 (d, J = 8.4 Hz, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 21.5, 48.9, 74.7, 80.4, 127.1, 127.4, 128.5, 128.7, 129.5, 136.9, 137.3, 143.6 ppm.

***N*-Methyl-*N*-(1-phenyl-2-propynyl)-*p*-toluenesulfonamide (7ac):** R_f = 0.40 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.31 (d, J = 2.4 Hz, 1 H), 2.43 (s, 3 H), 2.57 (s, 3 H), 6.05 (d, J = 2.4 Hz, 1 H), 7.29–7.38 (m, 5 H), 7.59 (d, J = 7.7 Hz, 2 H), 7.78 (d, J = 8.4 Hz, 2 H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 21.4, 29.5, 53.1, 76.67, 76.9, 127.6, 127.8, 128.3, 128.4, 129.3, 134.8, 135.4, 143.5 ppm. HRMS (EI): calcd. for $C_{17}H_{17}NO_2S$ 299.0980; found 299.0975.

Ethyl *N*-(1-Phenyl-2-propynyl)carbamate (7ad): R_f = 0.38 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.17 (t, J = 6.9 Hz, 3 H), 2.43 (d, J = 2.4 Hz, 1 H), 4.08 (q, J = 6.9 Hz, 2 H), 5.17 (br., 1 H), 5.62 (br., 1 H), 7.20–7.32 (m, 3 H), 7.43 (d, J = 7.2 Hz, 2 H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 14.5, 46.6, 61.4, 73.2, 81.8, 126.9, 128.2, 128.7, 138.4, 155.6 ppm. $C_{12}H_{13}NO_2$ (203.24): calcd. C 70.92, H 6.45, N 6.89; found C 70.93, H 6.29, N 6.84.

***N*-(1,3-Diphenyl-2-propynyl)-*p*-toluenesulfonamide (7bb):**[31] R_f = 0.37 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.31 (s, 3 H), 4.97 (d, J = 9.0 Hz, 1 H), 5.56 (d, J = 9.0 Hz, 1 H), 7.07–7.13 (m, 2 H), 7.21–7.40 (m, 8 H), 7.55 (d, J = 7.0 Hz, 2 H), 7.81 (d, J = 8.4 Hz, 2 H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 21.4, 49.8, 85.5, 86.7, 122.0, 127.3, 127.5, 128.1, 128.5, 128.6, 128.7, 129.6, 131.6, 137.4, 143.6 ppm.

***N*-Methyl-*N*-(1,3-diphenyl-2-propynyl)-*p*-toluenesulfonamide (7bc):** R_f = 0.47 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.31 (s, 3 H), 2.63 (s, 3 H), 6.23 (s, 1 H), 7.06–7.11 (m, 2 H), 7.22–7.42 (m, 8 H), 7.65 (d, J = 7.5 Hz, 2 H), 7.82 (d, J = 8.1 Hz, 2 H) ppm. $C_{23}H_{21}NO_2S$ (375.49): calcd. C 73.57, H 5.64, N 3.73; found C 73.18, H 5.73, N 3.68.

Benzyl *N*-(1,3-Diphenyl-2-propynyl)carbamate (7be):[16] R_f = 0.40 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 5.13 (br., 2 H), 5.42 (br., 1 H), 5.95 (br., 1 H), 7.22–7.40 (m, 11 H), 7.40–7.50 (m, 2 H), 7.50–7.60 (m, 2 H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 47.4, 67.2, 85.1, 87.0, 122.4, 127.0, 128.2, 128.3, 128.52, 128.55, 128.7, 131.8, 136.2, 139.1, 155.4 ppm.

***N*-(1,3-Diphenyl-2-propynyl)benzamide (7bg):**[13] R_f = 0.33 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 6.48 (d, J = 8.7 Hz, 1 H), 6.84 (br., 1 H), 7.28–7.51 (m, 11 H), 7.64 (d, J = 7.2 Hz, 2 H), 7.80 (d, J = 7.8 Hz, 2 H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 45.6, 85.1, 87.0, 122.4, 127.2, 128.2, 128.3, 128.6, 128.8, 131.79, 131.84, 133.8, 139.0, 166.2 ppm.

***N*-(1-Phenyl-2-nonynyl)-*p*-toluenesulfonamide (7db):**[31] R_f = 0.40 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.88 (t, J = 6.9 Hz, 3 H), 1.16–1.34 (m, 8 H), 1.94 (td, J = 6.9, 2.1 Hz, 2 H), 2.41 (s, 3 H), 5.08 (dd, J = 9.0, 2.1 Hz, 1 H), 5.28 (d, J = 9.0 Hz, 1 H), 7.21–7.32 (m, 5 H), 7.42–7.48 (m, 2 H), 7.76 (d, J = 8.1 Hz, 2 H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 14.0, 18.5, 21.5, 22.5, 28.3, 28.5, 31.3, 49.4, 76.6, 87.5, 127.3, 127.5, 128.1, 128.5, 129.4, 137.6, 138.2, 143.2 ppm.

***N*-Methyl-*N*-(1-phenyl-2-nonynyl)-*p*-toluenesulfonamide (7dc):** R_f = 0.57 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.88 (t, J = 6.9 Hz, 3 H), 1.18–1.32 (m, 8 H), 1.94–2.01 (m, 2 H), 2.43 (s, 3 H), 2.53 (s, 3 H), 6.01 (br., 1 H), 7.25–7.38 (m, 5 H), 7.58 (d, J = 7.2 Hz, 2 H), 7.79 (d, J = 8.1 Hz, 2 H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 14.0, 18.4, 21.5, 22.5, 28.3, 28.5, 29.6, 31.2, 53.7, 73.0, 89.4, 127.8, 128.01, 128.04, 128.3, 129.2, 135.1, 136.7, 143.1 ppm. HRMS (EI): calcd. for $C_{23}H_{29}NO_2S$ 383.1919; found 383.1925.

Ethyl *N*-(1-Phenyl-2-nonynyl)carbamate (7dd): R_f = 0.50 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.89 (t, J = 6.6 Hz, 3 H), 1.23 (t, J = 6.9 Hz, 3 H), 1.20–1.60 (m, 8 H), 2.23 (td, J = 6.9, 1.8 Hz, 2 H), 4.13 (q, J = 6.9 Hz, 2 H), 5.21 (br., 1 H), 5.66 (br., 1 H), 7.22–7.40 (m, 3 H), 7.50 (d, J = 7.2 Hz, 2 H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 14.0, 14.5, 18.7, 22.5, 28.49, 28.51, 31.2, 46.9, 61.1, 78.0, 85.7, 126.8, 127.8, 128.5, 139.9, 155.6 ppm. $C_{18}H_{25}NO_2$ (287.40): clacd. C 75.22, H 8.77, N 4.87; found C 75.19, H 8.44, N 4.76.

Ethyl *N*-Methyl-*N*-(1-phenyl-2-nonynyl)carbamate (7df): R_f = 0.55 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.90 (t, J = 6.6 Hz, 3 H), 1.20–1.60 (m, 11 H), 2.30 (td, J = 7.2, 2.1 Hz, 2 H), 2.71 (s, 3 H), 4.15–4.28 (m, 2 H), 6.23, 6.40 (br., 1 H), 7.23–7.37 (3 H), 7.37–7.52 (m, 2 H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 14.0, 14.7, 18.7, 22.5, 28.5, 28.7, 31.3, 51.5, 61.7, 75.8, 87.2, 127.4, 127.7, 128.3, 137.9, 156.7 ppm. HRMS (EI): calcd. for $C_{19}H_{27}NO_2$ 301.2042; found 301.2045.

***N*-[3-Phenyl-1-(2-phenylethyl)-2-propynyl]benzenesulfonamide (7ea):** R_f = 0.23 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.03–2.13 (m, 2 H), 2.83 (t, J = 7.8 Hz, 2 H), 4.33 (dt, J = 9.0, 6.9 Hz, 1 H), 4.92 (d, J = 9.0 Hz, 1 H), 7.06–7.11 (m, 2 H), 7.16–7.32 (m, 8 H), 7.41–7.54 (m, 3 H), 7.89–7.94 (m, 2 H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 31.7, 38.4, 46.0, 85.0, 86.7, 121.9, 126.2, 127.4, 128.1, 128.5, 129.0, 131.5, 132.7, 140.3, 140.5 ppm. HRMS (EI): calcd. for $C_{23}H_{21}NO_2S$ 375.1293; found 375.1278.

***N*-[3-Phenyl-1-(2-phenylethyl)-2-propynyl]-*p*-toluenesulfonamide (7eb):** R_f = 0.23 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.01–2.12 (m, 2 H), 2.32 (s, 3 H), 2.83 (t, J = 6.9 Hz, 2 H), 4.30 (dt, J = 9.3, 6.9 Hz, 1 H), 4.71 (d, J = 9.3 Hz, 1 H), 7.08 (dd, J = 7.8, 1.5 Hz, 2 H), 7.16–7.33 (m, 10 H), 7.78 (d, J = 8.4 Hz, 2 H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 21.4, 31.7, 38.3, 46.0, 84.9, 86.8, 122.1, 126.2, 127.5, 128.1, 128.4, 128.54, 128.56, 129.6, 131.5, 137.3, 140.6, 143.6 ppm. HRMS (EI): calcd. for $C_{24}H_{23}NO_2S$ 389.1450; found 389.1434.

***N*-Methyl-*N*-[3-phenyl-1-(2-phenylethyl)-2-propynyl]-*p*-toluenesulfonamide (7ec):** R_f = 0.47 (hexane/ethyl acetate = 3:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.06 (q, J = 7.8 Hz, 2 H), 2.32 (s, 3 H), 2.82 (s, 3 H), 2.81 (t, J = 7.8 Hz, 2 H), 4.92 (t, J = 7.8 Hz, 1 H), 7.01 (dd, J = 7.8, 1.5 Hz, 2 H), 7.15–7.35 (m, 10 H), 7.74 (J = 8.1 Hz, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 21.3, 29.7, 32.2, 35.8, 50.3, 84.5, 86.1, 122.1, 126.1, 127.9, 128.1, 128.3, 128.4, 128.5, 129.4, 131.4, 134.7, 140.8, 143.4 ppm. $C_{25}H_{25}NO_2S$ (403.54): calcd. C 74.41, H 6.24, N 3.47; found C 74.27, H 6.12, N 3.38.

Supporting Information (see footnote on the first page of this article): Copies of ^{1}H and ^{13}C NMR spectra of all compounds.

[1] For selected reviews on nucleophilic addition reactions, see: a) A. S. K. Hashmi, *Chem. Rev.* **2007**, *107*, 3180–3211; b) Y. Yamamoto, *J. Org. Chem.* **2007**, *72*, 7817–7831; c) Y. Yamamoto,

I. D. Gridnev, N. T. Patil, T. Jin, *Chem. Commun.* **2009**, 5075–5087; d) N. D. Shapiro, F. D. Toste, *Synlett* **2010**, 675–691.

[2] For selected reviews on cyclization reactions, see: a) M. Lautens, W. Klute, W. Tam, *Chem. Rev.* **1996**, *96*, 49–92; b) J. Montgomery, *Angew. Chem.* **2004**, *116*, 3980; *Angew. Chem. Int. Ed.* **2004**, *43*, 3890–3908; c) I. Nakamura, Y. Yamamoto, *Chem. Rev.* **2004**, *104*, 2127–2198; d) N. Agenet, O. Buisine, F. Slowinski, V. Gandon, C. Aubert, M. Malacria, in: *Organic Reactions* (Ed.: L. E. Overman), Wiley, New York, **2007**, vol. 68, pp. 1–302.

[3] For a recent review on catalytic nucleophilic addition reactions of terminal alkynes, see: C.-J. Li, *Acc. Chem. Res.* **2010**, *43*, 581–590.

[4] For a selected review on carbonyl propargylations, see: B. W. Gung, in: *Organic Reactions* (Ed.: L. E. Overman), Wiley, New York, **2004**, vol. 64, pp. 1–113.

[5] For a selected review on Sonogashira reactions, see: R. Chinchilla, C. Najera, *Chem. Rev.* **2007**, *107*, 874–922.

[6] For selected reviews on catalytic propargylic substitutions, see: a) G. W. Kabalka, M.-L. Yao, *Curr. Org. Synth.* **2008**, *5*, 28–32; b) Y. Miyake, S. Uemura, Y. Nishibayashi, *ChemCatChem* **2009**, *1*, 342–356; c) R. J. Detz, H. Hiemstra, J. H. van Maarseveen, *Eur. J. Org. Chem.* **2009**, 6263–6276.

[7] a) Y. Nishibayashi, I. Wakiji, M. Hidai, *J. Am. Chem. Soc.* **2000**, *122*, 11019–11020; b) Y. Nishibayashi, M. Yoshikawa, Y. Inada, M. Hidai, S. Uemura, *J. Am. Chem. Soc.* **2001**, *124*, 11846–11847; c) Y. Nishibayashi, Y. Inada, M. Yoshikawa, M. Hidai, S. Uemura, *Angew. Chem.* **2003**, *115*, 1533; *Angew. Chem. Int. Ed.* **2003**, *42*, 1495–1498; d) Y. Nishibayashi, M. D. Milton, Y. Inada, M. Yoshikawa, I. Wakiji, M. Hidai, S. Uemura, *Chem. Eur. J.* **2005**, *11*, 1433–1451; e) Y. Inada, M. Yoshikawa, M. D. Milton, Y. Nishibayashi, S. Uemura, *Eur. J. Org. Chem.* **2006**, 881–890.

[8] a) J. J. Kennedy-Smith, L. A. Young, F. D. Toste, *Org. Lett.* **2004**, *6*, 1325–1327; b) R. V. Ohri, A. T. Radosevich, K. J. Hrovat, C. Musich, D. Huang, T. R. Holman, F. D. Toste, *Org. Lett.* **2005**, *7*, 2501–2504.

[9] a) E. Bustelo, P. H. Dixneuf, *Adv. Synth. Catal.* **2005**, *347*, 393–397; b) C. Fischmeister, L. Toupet, P. H. Dixneuf, *New J. Chem.* **2005**, *29*, 765–768; c) E. Bustelo, P. H. Dixneuf, *Adv. Synth. Catal.* **2007**, *349*, 933–942.

[10] a) M. Georgy, V. Boucard, J. M. Campagne, *J. Am. Chem. Soc.* **2005**, *127*, 14180–14181; b) M. Georgy, V. Boucard, O. Debleds, C. D. Zotto, J. M. Campagne, *Tetrahedron* **2009**, *65*, 1758–1766.

[11] J. Liu, E. Muth, U. Flörka, G. Henkel, K. Merz, J. Sauvageau, E. Schwake, G. Dyker, *Adv. Synth. Catal.* **2006**, *348*, 456–462.

[12] Z.-P. Zhan, W.-Z. Yang, R.-F. Yang, J.-L. Yu, J.-P. Li, H.-J. Liu, *Chem. Commun.* **2006**, 3352–3354.

[13] Z.-P. Zhan, J.-L. Yu, H.-J. Liu, Y.-Y. Cui, R.-F. Yang, W.-Z. Yang, J.-P. Li, *J. Org. Chem.* **2006**, *71*, 8298–8301.

[14] H. Qin, N. Yamagiwa, S. Matsunaga, M. Shibasaki, *Angew. Chem.* **2007**, *119*, 413; *Angew. Chem. Int. Ed.* **2007**, *46*, 409–413.

[15] J. S. Yadav, B. V. S. Reddy, K. V. R. Rao, G. G. K. S. N. Kumar, *Tetrahedron Lett.* **2007**, *48*, 5573–5576.

[16] C. R. Reddy, P. P. Madhavi, A. S. Reddy, *Tetrahedron Lett.* **2007**, *48*, 7169–7172.

[17] P. Srihari, D. C. Bhunia, P. Sreedhar, S. S. Mandal, J. S. S. Reddy, J. S. Yadav, *Tetrahedron Lett.* **2007**, *48*, 8120–8124.

[18] W. Huang, J. Wang, Q. Shen, X. Zhou, *Tetrahedron* **2007**, *63*, 11636–11643.

[19] Y. Kuninobu, H. Ueda, K. Takai, *Chem. Lett.* **2008**, *37*, 878–879.

[20] M. Zhang, H. Yang, Y. Cheng, Y. Zhu, C. Zhu, *Tetrahedron Lett.* **2010**, *51*, 1176–1179.

[21] a) P. N. Chatterjee, S. Roy, *J. Org. Chem.* **2010**, *75*, 4413–4423; b) P. N. Chatterjee, S. Roy, *Tetrahedron* **2011**, *67*, 4569–4577.

[22] C. C. Silveira, S. R. Mendes, L. Wolf, G. M. Martins, *Tetrahedron Lett.* **2010**, *51*, 4560–4562.

[23] S. Maiti, S. Biswas, U. Jana, *Synth. Commun.* **2011**, *41*, 243–254.

[24] a) J. S. Yadav, B. V. S. Reddy, T. Pandurangam, K. V. R. Rao, K. Praneeth, G. G. K. S. N. Kumar, C. Madavi, A. C. Kumar, *Tetrahedron Lett.* **2008**, *49*, 4296–4301; b) J. S. Yadav, B. V. S. Reddy, T. S. Rao, B. B. M. Krishna, G. G. K. S. N. Kumar, *Chem. Lett.* **2007**, *36*, 1472–1473; c) P. Srihari, J. S. S. Reddy, D. C. Bhunia, S. S. Mandal, J. S. Yadav, *Synth. Commun.* **2008**, *38*, 1448–1455.

[25] a) R. Sanz, A. Martínez, J. M. Álvarez-Gutiérrez, F. Rodríguez, *Eur. J. Org. Chem.* **2006**, 1383–1386; b) R. Sanz, D. Miguel, A. Martínez, J. M. Álvarez-Gutiérrez, F. Rodríguez, *Org. Lett.* **2007**, *9*, 727–730; c) R. Sanz, D. Miguel, A. Martínez, M. Gohain, P. García-García, M. A. Fernández-Rodríguez, E. Álvarez, F. Rodríguez, *Eur. J. Org. Chem.* **2010**, 7027–7039.

[26] For selected papers on the application of tin(II) chloride as a weak Lewis acid catalyst in organic syntheses, see: a) T. Mukaiyama, K. Wariishi, Y. Saito, M. Hayashi, S. Kobayashi, *Chem. Lett.* **1988**, 1101–1104; b) K. L. Ford, E. J. Roskamp, *Tetrahedron Lett.* **1992**, *33*, 1135–1138; c) C. S. Cho, D. T. Kim, H.-J. Choi, T.-J. Kim, S. C. Shim, *Bull. Korean Chem. Soc.* **2002**, *23*, 539–540; d) A. Bandyopadhyay, N. Agrawal, S. M. Mali, S. V. Jadhav, H. N. Gopi, *Org. Biomol. Chem.* **2010**, *8*, 4855–4860; e) L. Nagarapu, R. Bantu, R. G. Puligoundla, *Eur. J. Chem.* **2011**, *2*, 260–265.

[27] J. P. Takahara, Y. Masuyama, Y. Kurusu, *J. Am. Chem. Soc.* **1992**, *114*, 2577–2586.

[28] Y. Masuyama, Y. Kaneko, Y. Kurusu, *Tetrahedron Lett.* **2004**, *45*, 8969–8971.

[29] Y. Masuyama, T. Chiyo, Y. Kurusu, *Synlett* **2005**, 2251–2253.

[30] M. M. Midland, *J. Org. Chem.* **1975**, *40*, 2250–2252.

[31] L. Zani, S. Alesi, P. G. Cozzi, C. Bolm, *J. Org. Chem.* **2006**, *71*, 1558–1562.

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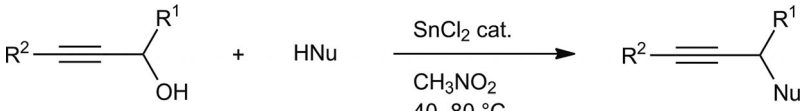

R^1 = Ph, 4-ClC_6H_4, $PhCH_2CH_2$
R^2 = H, Ph, C_6H_{13}

A weak Lewis acid, tin(II) chloride, which is insensitive to water and air, functioned as a catalyst for the propargylic substitution of secondary propargylic alcohols with carbon nucleophiles, such as electron-rich arenes, heteroarenes, and 1,3-dicarbonyl compounds, and nitrogen nucleophiles, such as sulfonamides, carbamates, and carboxamides.

Keywords: Nucleophilic substitution / Propargylation / Lewis acids / Tin / Alkynes

