Pd-catalyzed decarboxylative alkynylation of alkynyl carboxylic acids with arylsulfonyl hydrazides via desulfinative process

Sheng Chang\textsuperscript{ab1}, Ying Liu\textsuperscript{a}, Shu Zhu Yin\textsuperscript{c}, Lin Lin Dong\textsuperscript{c}, Jian Feng Wang\textsuperscript{d}\textsuperscript{*}

\textsuperscript{a}College of Pharmacy, Jilin Medical University, Jilin, Jilin, 132013, China
\textsuperscript{b}State Key Laboratory of Medicinal Chemical Biology, NanKai University, Tianjin, 300071, China
\textsuperscript{c}College of Pharmacy, Yanbian University, Yanji, Jilin, 133002, China
\textsuperscript{d}Department of Radiotherapy, China-Japan Union Hospital of Jilin University, Changchun, Jilin, 130033, China

Corresponding author. Tel.: +86 432 6456 0532.
E-mail address: jmu_changsheng@126.com, jfwang@jlu.edu.cn

Supporting Materials

Content

General .................................................................2
Preparation and Characterization of Starting Materials..............2
Typical procedure for the product........................................3
Optimization table of bases, solvents, etc.................................4
Characterization data of the product.....................................5
References.............................................................11
Copies of NMR Spectra...............................................12
General

Reagents and solvents were used as it is obtained from commercial vendors. All reactions were performed in a 100 mL autoclave. Products were purified by column chromatography on silica gel (200–300) mesh. $^1$H and $^{13}$C NMR spectra were obtained on Bruker–400 MHz spectrometers using tetramethylsilane as internal standard in CDCl$_3$. Chemical shifts of $^1$H NMR and $^{13}$C NMR are reported as δ values relative to TMS and CDCl$_3$ respectively. Chemical shifts were reported in parts per million (ppm, δ). Proton coupling patterns are described as singlet (s), doublet (d), triplet (t), quartet (q), multiplet (m), and broad resonances (br). HRMS (EI) data were collected on High Resolution mass spectrometer. All products are known compounds and are in accord with characterization in literature.

Preparation and Characterization of Starting Materials

**General procedure for preparation of alkynyl carboxylic acids:**

Step 1: Triphenylphosphine (20 mmol) was added to a well-stirred solution of carbon tetrabromide (10 mmol) in dry dichloromethane (50 mL). Upon addition of aldehyde (5 mmol), the solution slowly faded away. The reaction mixture was stirred at ambient temperature for 6 hours till completion (TLC monitoring). After removal of solvent, the residue was repeatedly triturated with hexane (5 x 25 mL) and hexane solution was concentrated. This cycle was continued three times. Finally the mixture was subjected to column chromatography (silica gel 60-120 mesh, eluent hexane) to afford the (2,2-dibromovinyl)arene.

Step 2: A solution of (2,2-dibromovinyl)arene (6 mmol) in 10 mL of dry THF at –78 °C was treated with a solution of $n$-BuLi in hexane (1.6 M, 7.5 mL, 12 mmol) under Nitrogen atmosphere. After stirring for 1h at –78 °C, the reaction mixture was warmed to 25 °C during 1 h, and again cooled to –60 °C. Solid carbon dioxide (5 g) was added to the above solution at –60 °C and the mixture was allowed to warm gradually to room temperature. The mixture was poured into water, and ethyl acetate was added. The aqueous layer was separated and washed further with ethyl acetate. The aqueous part was acidified with 6(N) HCl and extracted with ethyl acetate (3 x 50 mL). The organic layer was washed with brine.
and dried over anhydrous magnesium sulfate. Evaporation of solvent afforded pure arylpropiolic acid.

Typical procedure for the product

Cross-coupling of alkynyl carboxylic acids and arylsulfonyl hydrazides:

A mixture of alkynyl carboxylic acids (1.0 mmol), arylsulfonyl hydrazides (1.1 mmol), Pd(dppf)Cl₂ (5 mol%), P(OPh)₃ (0.1 mmol), K₂CO₃ (1.5 mmol) in DMA (1 mL) was stirred at 80 °C for 12 h under air. Afterward, the mixture was cooled to room temperature, filtered through a pad of celite after the addition of water (1 mL). The reaction mixture was extracted by Et₂O (2 mL) for three times. And then the organic phase was combined and evaporated under reduced pressure, and the residue was subjected to flash column chromatography to obtain the desired product.

Optimization table of bases, solvents, etc

Then, a series of commercially available bases (e.g., KOAc, Cs₂CO₃, K₂CO₃, Et₃N, and Na₂CO₃) were checked, and the product could be obtained in a good yield of 88% by using K₂CO₃ as the base (Table SI, entries 1–5). Solvent screening showed that DMA was superior to DMSO and DMF (Table SI, entries 6–7). On the contrary, other solvents such as DME and DCE were found to be ineffective (Table SI, entries 8–9). Finally, the efficiency of palladium-catalyzed coupling was reduced under 0.1 M concentration (Table SI, entry 10). The reaction A temperature screening suggested that the transformation at 80°C delivered the coupling product in the highest isolated yield (Table SI, entries 11–13).
Table SI. Bases and solvent selection of palladium-catalyzed coupling of phenylsulfanyl hydrazide and phenylpropionic acid

\[
\text{COOH} \quad \overset{\text{S}}{\text{O}} \text{NHNH}_2 \quad \overset{\text{Pd(dppf)Cl}_2 \text{P(OPh)}_3}{\text{base, solvent}} \quad 80^\circ\text{C}, 12 \text{ h, air} \quad \text{COOH} \quad \text{COOH}
\]

<table>
<thead>
<tr>
<th>entry</th>
<th>base</th>
<th>solvent</th>
<th>Temperature (°C)</th>
<th>yield (%) b</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>K\textsubscript{2}CO\textsubscript{3}</td>
<td>DMA</td>
<td>80</td>
<td>88</td>
</tr>
<tr>
<td>2</td>
<td>KOAc</td>
<td>DMA</td>
<td>80</td>
<td>81</td>
</tr>
<tr>
<td>3</td>
<td>Cs\textsubscript{2}CO\textsubscript{3}</td>
<td>DMA</td>
<td>80</td>
<td>72</td>
</tr>
<tr>
<td>4</td>
<td>Et\textsubscript{3}N</td>
<td>DMA</td>
<td>80</td>
<td>55</td>
</tr>
<tr>
<td>5</td>
<td>Na\textsubscript{2}CO\textsubscript{3}</td>
<td>DMA</td>
<td>80</td>
<td>78</td>
</tr>
<tr>
<td>6</td>
<td>K\textsubscript{2}CO\textsubscript{3}</td>
<td>DMSO</td>
<td>80</td>
<td>85</td>
</tr>
<tr>
<td>7</td>
<td>K\textsubscript{2}CO\textsubscript{3}</td>
<td>DMF</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>8</td>
<td>K\textsubscript{2}CO\textsubscript{3}</td>
<td>DME</td>
<td>80</td>
<td>38</td>
</tr>
<tr>
<td>9</td>
<td>K\textsubscript{2}CO\textsubscript{3}</td>
<td>DCE</td>
<td>80</td>
<td>35</td>
</tr>
<tr>
<td>10</td>
<td>K\textsubscript{2}CO\textsubscript{3}</td>
<td>DMA</td>
<td>80</td>
<td>46 c</td>
</tr>
<tr>
<td>11</td>
<td>K\textsubscript{2}CO\textsubscript{3}</td>
<td>DMA</td>
<td>60</td>
<td>22</td>
</tr>
<tr>
<td>12</td>
<td>K\textsubscript{2}CO\textsubscript{3}</td>
<td>DMA</td>
<td>70</td>
<td>57</td>
</tr>
<tr>
<td>13</td>
<td>K\textsubscript{2}CO\textsubscript{3}</td>
<td>DMA</td>
<td>90</td>
<td>87</td>
</tr>
</tbody>
</table>

a Reaction conditions: phenylpropionic acid (1.0 mmol), phenylsulfanyl hydrazide (1.1 mmol), Pd(dppf)Cl\textsubscript{2} (0.05 mmol), P(OPh)\textsubscript{3} (0.1 mmol), base (1.5 mmol), solvent (1 mL), 80 °C, 12 h, under air. b Isolated yields. c solvent (10 mL).
Characterization data of the product

1,2-bis(4-methoxyphenyl)ethyne (2a): White solid, mp: 146−149 °C (ref 1 147−148 °C). \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 7.48 (d, \(J = 8.8\) Hz, 4H), 6.86 (d, \(J = 8.8\) Hz, 4H), 3.81 (s, 6H). \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 159.4, 132.9, 124.4, 115.7, 114.0, 88.0, 55.3. HRMS (EI) Calcd for C\(_{16}\)H\(_{15}\)O\(_2\) [M+H]\(^+\), 239.1067; found, 239.1076.

1-methoxy-4-(p-tolylethynyl)benzene (2b): White solid, mp: 126−128 °C (ref 2 126−130 °C). \(^1\)HNMR (400 MHz, CDCl\(_3\)) \(\delta\) 7.47 (d, \(J = 8.4\) Hz, 2H), 7.41 (d, \(J = 8.0\) Hz, 2H), 7.15 (d, \(J = 8.0\) Hz, 2H), 6.89–6.86 (m, 2H), 3.84 (s, 3H), 2.38 (s, 3H). \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 159.6, 138.0, 133.1, 131.4, 129.2, 120.6, 115.6, 114.0, 88.6, 88.2, 55.4, 21.5. HRMS (EI) Calcd for C\(_{16}\)H\(_{15}\)O [M+H]\(^+\), 223.1117; found, 223.1111.

(4-ethyl-methoxyphenyl)ethynyl)benzene (2c): White solid, mp: 116−117 °C. \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 7.46 (dd, \(J = 12.4, 8.4\) Hz, 4H), 7.16 (d, \(J = 8.0\) Hz, 2H), 6.86 (d, \(J = 8.8\) Hz, 2H), 3.84 (s, 3H), 2.65 (q, \(J = 7.6\) Hz, 2H), 1.23 (t, \(J = 7.6\) Hz, 3H). \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 160.9, 145.8, 134.4, 132.9, 129.3, 122.2, 117.1, 115.4, 90.1, 89.6, 56.7, 30.2, 16.8. HRMS (EI) Calcd for C\(_{17}\)H\(_{17}\)O [M+H]\(^+\), 237.1274; found, 237.1266.

1-butyl-4-((4-methoxyphenyl)ethynyl)benzene (2d): White solid, mp: 105−107 °C. \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 7.48 (d, \(J = 8.8\) Hz, 2H), 7.43 (d, \(J = 8.0\) Hz, 2H), 7.14 (d, \(J = 8.0\) Hz, 2H), 6.86 (d, \(J = 8.8\) Hz, 2H), 3.82 (s, 3H), 2.66 – 2.57 (m, 2H), 1.58 (dd, \(J = 15.2, 7.6\) Hz, 2H), 1.37 (dd, \(J = 14.8, 7.6\) Hz, 2H), 0.94 (t, \(J = 7.2\) Hz, 3H). \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 159.5, 143.0, 133.0, 131.4, 128.4, 120.7, 115.7, 114.0, 88.7, 88.2, 55.3, 35.6, 33.4, 22.3, 13.9. HRMS (EI) Calcd for C\(_{19}\)H\(_{21}\)O [M+H]\(^+\), 265.1587; found, 265.1579.

1-Methoxy-4-((4-nitrophenyl)ethynyl)benzene (2e): Yellow solid, mp: 122−123 °C (ref 3 121 °C). \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 8.09 (d, \(J = 8.8\) Hz, 2H), 7.51 (d, \(J = 8.8\) Hz, 2H), 7.40 (d, \(J = 8.8\) Hz, 2H), 6.81 (d, \(J = 8.8\) Hz, 2H), 3.75 (s, 3H). \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 160.7, 147.0, 133.9, 132.4, 131.2, 124.0, 114.6, 95.6, 87.0, 78.1, 55.7. HRMS (EI) Calcd for C\(_{15}\)H\(_{12}\)NO\(_3\) [M+H]\(^+\), 254.0812; found, 254.0819.
1-methoxy-4-(m-tolylethynyl)benzene (2f): White solid, mp: 42–44 °C (ref 43–44°C). $^1$H NMR (400 MHz, CDCl$_3$) δ 7.47 (d, $J = 8.8$ Hz, 2H), 7.38 – 7.28 (m, 2H), 7.23 (t, $J = 7.6$ Hz, 1H), 7.12 (d, $J = 7.6$ Hz, 1H), 6.87 (d, $J = 8.8$ Hz, 2H), 3.82 (s, 3H), 2.34 (s, 3H). $^{13}$C NMR (100 MHz, CDCl$_3$) δ 159.6, 138.0, 133.0, 132.0, 128.8, 128.5, 128.2, 123.5, 115.5, 114.0, 89.0, 88.2, 55.3, 21.2. HRMS (EI) Calcd for C$_{16}$H$_{15}$O$^+$, 223.1117; found, 223.1125.

1-methoxy-4-(m-bromoethynyl)benzene (2g): White solid, mp: 67–69 °C (ref 65–67°C). $^1$H NMR (400 MHz, CDCl$_3$) δ 7.45 (d, $J = 8.8$ Hz, 2H), 7.12 (t, $J = 7.6$ Hz, 1H), 6.92 (d, $J = 7.6$ Hz, 1H), 6.90–6.83 (m, 3H), 6.65 (dd, $J = 8.0$, 1.6 Hz, 1H), 3.82 (s, 3H). $^{13}$C NMR (100 MHz, CDCl$_3$): δ 161.0, 147.7, 134.5, 130.7, 125.7, 123.4, 119.2, 116.9, 116.5, 115.4, 90.2, 89.7, 56.7. HRMS (EI) Calcd for C$_{15}$H$_{12}$ClO$^+$, 243.0571; found, 243.0562.

2-((4-methoxyphenyl)ethynyl)naphthalene (2h): White solid, mp: 120–122 °C (ref 122–124 °C). $^1$H NMR (400 MHz, CDCl$_3$) δ 8.02 (s, 1H), 7.80–7.77 (m, 3H), 7.56–7.46 (m, 5H), 6.89 (d, $J = 8.0$ Hz, 2H), 3.83 (s, 3H). $^{13}$C NMR (100 MHz, CDCl$_3$): δ 159.7, 133.3, 133.1, 132.7, 131.2, 128.5, 128.1, 127.8, 127.7, 126.4, 121.0, 115.3, 114.1, 89.7, 88.5, 55.2. HRMS (EI) Calcd for C$_{19}$H$_{15}$O$^+$, 259.1117; found, 259.1109.

2-(4-Methoxyphenyl)benzofuran (2i): White crystals, mp: 140–143 °C (ref 143–144 °C). $^1$H NMR (400 MHz, CDCl$_3$) δ 7.70 (td, $J = 10$, 2.4 Hz, 2H), 7.49–7.37 (m, 3H), 7.21–7.06 (m, 2H), 6.88 (td, $J = 32$, 2.0 Hz, 2H), 6.78 (d, $J = 0.8$ Hz, 1H), 3.75 (s, 3H). $^{13}$C NMR (100 MHz, CDCl$_3$): δ 160.1, 156.3, 154.8, 129.6, 126.6, 123.9, 123.6, 123.0, 120.8, 114.4, 111.1, 99.9, 55.5. HRMS (EI) Calcd for C$_{17}$H$_{13}$O$_2$ [M+H]$^+$, 249.0910; found, 249.0916.

1-(hex-1-ynyl)-4-methoxybenzene (2j): Colorless liquid. $^1$HNMR (400 MHz, CDCl$_3$) δ 7.34 (d, $J = 8.8$ Hz, 2H), 6.82 (d, $J = 8.8$ Hz, 2H), 3.81 (s, 3H), 2.38 (d, $J = 8.8$, 5.2, 2H), 1.62–1.54 (m, 2H), 1.51–1.41 (m, 2H), 0.93 (dd, $J = 15.6$, 8.4, 3H). $^{13}$C NMR (100 MHz, CDCl$_3$) δ 157.8, 131.8, 115.4, 112.8, 87.6, 79.2, 54.3, 30.9, 21.1, 18.4, 13.2. HRMS (EI) Calcd for C$_{13}$H$_{15}$O [M+H]$^+$, 189.1274; found, 189.1269.

1-(hept-1-ynyl)-4-methoxybenzene (2k): Colorless liquid. $^1$H NMR (400 MHz, CDCl$_3$) δ 7.36 (d, $J = 8.8$ Hz, 2H), 6.83 (d, $J = 8.8$ Hz, 2H), 3.78 (s, 2H), 2.41 (t, $J = 7.2$ Hz, 1H), 1.69 – 1.56 (m,
1H), 1.43 (dddt, J = 28.8, 21.6, 14.4, 7.2 Hz, 2H), 0.95 (t, J = 7.2 Hz, 2H). 13C NMR (100 MHz, CDCl3) δ 159.0, 132.9, 116.4, 113.8, 88.8, 80.3, 55.2, 31.2, 28.6, 22.3, 19.4, 14.0. HRMS (EI) Caled for C14H19O [M+H]+, 203.1430; found, 203.1440.

1-(oct-1-ynyl)-4-methoxybenzene (2l): Colorless liquid. 1H NMR (400 MHz, CDCl3) δ 7.33 (d, J = 8.8 Hz, 2H), 6.81 (d, J = 8.8 Hz, 2H), 3.78 (s, 3H), 2.37 (t, J = 7.2 Hz, 2H), 1.57 (dd, J = 12.4, 4.8, 2H), 1.49–1.40 (m, 2H), 1.34–1.30 (m, 4H), 0.91 (t, J = 7.2 Hz, 3H). 13C NMR (100 MHz, CDCl3) δ 159.1, 132.9, 116.5, 113.8, 96.8, 78.7, 55.4, 31.4, 28.8, 28.5, 22.6, 19.5, 14.1. HRMS (EI) Calcd for C15H21O [M+H]+, 217.1587; found, 217.1579.

1-(3, 3-dimethyl-1-butynyl)-4-methoxybenzene (2m): A pale yellow powder, mp: 37–38 °C (ref 7 39 °C). 1H NMR (400 MHz, CDCl3) δ 7.41–7.27 (m, 2H), 6.78 (d, J = 8.8 Hz, 2H), 3.78 (s, 3H), 1.31 (s, 9H). 13C NMR (100 MHz, CDCl3) δ 158.8, 132.9, 116.4, 113.7, 96.8, 78.7, 55.4, 31.2, 27.8. HRMS (EI) Calcd for C13H17O [M+H]+, 189.1274; found, 189.1266.

1-methyl-4-(phenylethynyl)benzene (3a): White powder, mp: 74–75 °C (ref 8 72–73 °C). 1H NMR (400 MHz, CDCl3) δ 7.56–7.53 (m, 2H), 7.44 (d, J = 8.0 Hz, 2H), 7.34 (d, J = 6.4 Hz, 3H), 7.17 (d, J = 8.0 Hz, 2H), 2.39 (s, 3H). 13C NMR (100 MHz, CDCl3) δ 139.8, 133.0, 132.9, 129.8, 129.5, 124.9, 121.6, 91.0, 90.2, 22.9. HRMS (EI) Calcd for C15H13 [M+H]+, 193.1012; found, 193.1020.

1-ethyl-4-(phenylethynyl)benzene (3b): White powder, mp: 30–33 °C (ref 8 32–33°C). 1H NMR (400 MHz, CDCl3) δ 7.65 – 7.58 (m, 2H), 7.51 (d, J = 8.0 Hz, 2H), 7.34 (d, J = 6.4 Hz, 3H), 7.22 (d, J = 8.0 Hz, 2H), 2.72 (q, J = 7.6 Hz, 2H), 1.30 (t, J = 7.6 Hz, 3H). 13C NMR (100 MHz, CDCl3) δ 146.2, 133.1, 133.1, 129.8, 129.6, 129.4, 125.0, 122.0, 91.1, 90.3, 30.3, 16.8. HRMS (EI) Calcd for C16H15[M+H]+, 207.1168; found, 207.1162.

2-diphenylethyne (3c): White powder, mp: 59–60 °C (ref 8 58–59 °C). 1H NMR (400 MHz, CDCl3) δ 7.54 (dd, J = 7.2, 2.0 Hz, 4H), 7.35 (d, J = 5.2 Hz, 2H). 13C NMR (100 MHz, CDCl3) δ 133.1, 129.8, 129.7, 124.7, 90.8. HRMS (EI) Calcd for C14H11 [M+H]+, 179.0855; found, 179.0851.
1-methoxy-4-(phenylethynyl)benzene (3d): White solid, mp: 56–58 °C (ref 8 57–59 °C)  
$^1$H NMR (400 MHz, CDCl$_3$) δ 7.52 (dd, $J = 7.6, 1.6$ Hz, 2H), 7.48 (d, $J = 8.8$ Hz, 2H), 7.35 (d, $J = 7.2$ Hz, 3H), 6.89 (d, $J = 8.8$ Hz, 2H), 3.84 (s, 3H).  
$^{13}$C NMR (100 MHz, CDCl$_3$) δ 159.6, 133.1, 131.4, 128.3, 127.8, 123.7, 115.4, 114.0, 89.5, 88.1, 55.4. HRMS (EI) Calcd for C$_{15}$H$_{13}$O [M+H]$^+$, 209.0961; found, 209.0966.

$^1$H NMR (400 MHz, CDCl$_3$) δ 8.23 (d, $J = 8.8$ Hz, 2H), 7.66 (d, $J = 8.8$ Hz, 2H), 7.56 (dd, $J = 6.4, 3.2$ Hz, 2H), 7.38 (dd, $J = 5.2, 1.6$ Hz, 3H).  
$^{13}$C NMR (100 MHz, CDCl$_3$) δ 148.4, 133.7, 133.3, 131.7, 130.7, 130.0, 125.1, 123.5, 96.2, 89.0. HRMS (EI) Calcd for C$_{14}$H$_{10}$NO$_2$ [M+H]$^+$, 224.0706; found, 224.0713.

1-chloro-4-(phenylethynyl)benzene (3f): White solid, mp: 83–85 °C (ref 8 83–84 °C).  
$^1$H NMR (400 MHz, CDCl$_3$) δ 7.53 (dd, $J = 6.4, 3.2$ Hz, 2H), 7.45 (d, $J = 8.4$ Hz, 2H), 7.38 – 7.28 (m, 5H).  
$^{13}$C NMR (100 MHz, CDCl$_3$) δ 132.8, 132.5, 131.6, 129.3, 128.7, 128.5, 128.4, 128.5, 121.8, 81.6. HRMS (EI) Calcd for C$_{14}$H$_{10}$Cl [M+H]$^+$, 213.0466; found, 213.0461.

1-(phenylethynyl)-4-(trifluoromethyl)benzene (3g): White solid, mp: 102–105 °C (ref 10 103–104 °C).  
$^1$H NMR (400 MHz, CDCl$_3$) δ 7.64 (d, $J = 8.8$ Hz, 2H), 7.61 (d, $J = 8.8$ Hz, 2H), 7.54 (dd, $J = 6.0, 3.6$ Hz, 2H), 7.42–7.34 (m, 3H).  
$^{13}$C NMR (100 MHz, CDCl$_3$) δ 133.2, 133.2, 130.3, 129.9, 126.7, 126.7, 124.0, 124.0, 93.2, 89.4. HRMS (EI) Calcd for C$_{15}$H$_{10}$F$_3$ [M+H]$^+$, 247.0729; found, 247.0722.

1-(4-(phenylethynyl)phenyl)ethanone (3h): White solid, mp: 97–99 °C (ref 11 98–99 °C).  
$^1$H NMR (400 MHz, CDCl$_3$) δ 7.95 (d, $J = 8.4$ Hz, 2H), 7.62 (d, $J = 8.4$ Hz, 2H), 7.58–7.52 (m, 2H), 7.42–7.34 (m, 3H), 2.61 (s, 3H).  
$^{13}$C NMR (100 MHz, CDCl$_3$) δ 198.8, 137.6, 133.2, 133.2, 130.3, 129.9, 126.7, 126.7, 124.0, 124.0, 94.2, 90.1, 28.1. HRMS (EI) Calcd for C$_{16}$H$_{13}$O [M+H]$^+$, 221.0961; found, 221.0953.

1-ethyl-4-(phenylethynyl)benzoate (3i): White solid, mp: 77–79 °C (ref 11 78–79 °C).  
$^1$H NMR (400 MHz, CDCl$_3$) δ 8.02 (d, $J = 8.4$ Hz, 2H), 7.58 (d, $J = 8.4$ Hz, 2H), 7.54 (dd, $J = 6.4, 3.2$ Hz, 2H), 7.40–7.33 (m, 3H), 4.38 (q, $J = 7.2$ Hz, 2H), 1.42 (t, $J = 7.2$ Hz, 3H).  
$^{13}$C NMR (100 MHz,
CDCl$_3$ $\delta$ 150.3, 134.5, 133.9, 133.1, 130.6, 129.8, 124.3, 123.5, 122.3, 91.6, 89.3, 54.8, 15.6. HRMS (EI) Calcd for C$_{15}$H$_{10}$O$_2$ [M+H]$^+$, 251.1067; found, 251.1061.

1-(phenylethynyl)-4-(trifluoromethoxy)benzene (3j): White solid, mp:69–71 °C (ref 12 68–70 °C). $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.56 (d, $J = 8.8$ Hz, 2H), 7.55 – 7.51 (m, 2H), 7.39 – 7.34 (m, 3H), 7.21 (d, $J = 8.0$ Hz, 2H). $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 150.3, 134.5, 133.1, 130.0, 129.8, 124.3, 123.5, 122.3, 91.6, 89.3. HRMS (EI) Calcd for C$_{15}$H$_{10}$F$_3$O [M+H]$^+$, 263.0678; found, 263.0673.

1-bromo-4-(phenylethynyl)benzene (3k): White solid, mp:84–85 °C (ref 13 82–83 °C). $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.53 (dd, $J = 6.4$, 2.8 Hz, 2H), 7.47 (d, $J = 8.4$ Hz, 2H), 7.38 (d, $J = 8.4$ Hz, 2H), 7.36 – 7.33 (m, 3H). $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 133.0, 132.5, 131.7, 131.6, 129.2, 128.5, 128.4, 128.3, 123.0, 121.8, 90.5, 88.3. HRMS (EI) Calcd for C$_{14}$H$_{10}$Br [M+H]$^+$, 256.9960; found, 256.9963.

1-methoxy-3-(phenylethynyl)benzene (3l): White solid, mp:79–80 °C (ref 8 77–78 °C). $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.61–7.53 (m, 2H), 7.43 – 7.35 (m, 3H), 7.32 – 7.26 (m, 2H), 7.15 (d, $J = 7.6$ Hz, 1H), 7.08 (s, 1H), 6.91 (dd, $J = 8.4$, 2.4 Hz, 1H), 3.84 (s, 3H). $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 160.8, 133.6, 130.8, 129.8, 129.7, 125.7, 125.6, 117.8, 116.4, 90.8, 90.6, 56.7. HRMS (EI) Calcd for C$_{15}$H$_{13}$O [M+H]$^+$, 209.0961; found, 209.0955.

1-methyl-3-(phenylethynyl)benzene (3m): White solid, mp:70–72 °C (ref 4 71–73 °C). $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.61 (dd, $J = 7.6$, 1.6 Hz, 2H), 7.42 (dd, $J = 11.6$, 8.8 Hz, 5H), 7.28 (t, $J = 7.6$ Hz, 1H), 7.21 (d, $J = 7.6$ Hz, 1H), 2.42 (s, 3H). $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 139.5, 133.1, 130.7, 130.2, 129.8, 129.7, 124.9, 124.6, 91.1, 90.6, 22.7. HRMS (EI) Calcd for C$_{15}$H$_{13}$ [M+H]$^+$, 193.1012; found, 193.1008.

1-(phenylethynyl)-3-(trifluoromethyl)benzene (3n): White solid, mp:105–108 °C (ref 14 105-106 °C). $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.81 (s, 1H), 7.71 (d, $J = 7.6$ Hz, 1H), 7.62 – 7.52 (m, 3H), 7.48 (t, $J = 7.6$ Hz, 1H), 7.40 – 7.33 (m, 3H). $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 136.1, 133.1, 130.3, 130.2, 129.9, 126.2, 125.7, 124.0, 92.3, 89.2. HRMS (EI) Calcd for C$_{15}$H$_{10}$F$_3$O [M+H]$^+$, 263.0678; found, 263.0670.
1-iodo-3-(phenylethynyl)benzene (3o): White solid, mp:44−47 °C (ref 15 45−47 °C). $^1$H NMR (400 MHz, CDCl$_3$) δ 7.91 (s, 1H), 7.68 (d, $J = 8.0$ Hz, 1H), 7.55 − 7.47 (m, 3H), 7.39 − 7.33 (m, 3H), 7.07 (t, $J = 7.6$ Hz, 1H). $^{13}$C NMR (100 MHz, CDCl$_3$) δ 141.6, 138.7, 133.1, 132.1, 131.3, 130.0, 129.8, 126.8, 124.2, 95.1, 92.1, 89.1. HRMS (El) Calcd for C$_{14}$H$_{10}$I $[M+H]^+$, 304.9822; found, 304.9805.

1-methoxy-2-(phenylethynyl)benzene (3p): White solid, mp:139−142 °C (ref 16 138−140 oC). $^1$H NMR (400 MHz, CDCl$_3$) δ 7.55 (dd, $J = 7.6$, 2.0 Hz, 2H), 7.51 (dd, $J = 7.6$, 1.6 Hz, 1H), 7.39 − 7.27 (m, 4H), 6.92 (dd, $J = 17.2$, 8.0 Hz, 2H), 3.91 (s, 3H). $^{13}$C NMR (100 MHz, CDCl$_3$) δ 160.0, 133.6, 131.7, 129.7, 128.2, 128.1, 123.6, 120.4, 112.5, 93.5, 85.7, 55.9. HRMS (EI) Calcd for C$_{15}$H$_{13}$O $[M+H]^+$, 209.0961; found, 209.0969.

1-methyl-2-(phenylethynyl)benzene (3q): White solid, 28−29°C. $^1$H NMR (400 MHz, CDCl$_3$) δ 7.62 (d, $J = 6.8$ Hz, 2H), 7.56 (d, $J = 7.6$ Hz, 1H), 7.42 (d, $J = 6.4$ Hz, 3H), 7.28 (d, $J = 4.4$ Hz, 2H), 7.22 (dt, $J = 8.4$, 4.4 Hz, 1H), 2.58 (s, 3H). $^{13}$C NMR (100 MHz, CDCl$_3$) δ 140.2, 131.8, 131.5, 129.5, 128.4, 128.3, 128.2, 125.6, 123.6, 123.1, 93.4, 88.4, 20.7. HRMS (El) Calcd for C$_{15}$H$_{13}$ [M+H]$^+$, 193.1012; found, 193.1017.

1-chloro-2-(phenylethynyl)benzene (3r): White solid, 33−34°C. $^1$H NMR (400 MHz, CDCl$_3$) δ 7.62 (td, $J = 8.0$, 3.6 Hz, 3H), 7.49 − 7.43 (m, 1H), 7.40 (dd, $J = 4.8$, 1.6 Hz, 3H), 7.30 − 7.25 (m, 2H). $^{13}$C NMR (100 MHz, CDCl$_3$) δ 136.0, 133.2, 132.5, 131.8, 129.3, 129.3, 128.7, 128.5, 128.4, 126.5, 123.3, 123.0, 95.1, 89.1. HRMS (El) Calcd for C$_{14}$H$_{10}$Cl $[M+H]^+$, 213.0466; found, 213.0471.

1-trifluoromethyl-2-(phenylethynyl)benzene (3s): White solid, 26−28°C. $^1$H NMR (400 MHz, CDCl$_3$) δ 7.68 (t, $J = 8.4$ Hz, 2H), 7.61 − 7.55 (m, 2H), 7.54 − 7.50 (m, 1H), 7.42 (t, $J = 7.6$ Hz, 1H), 7.40 − 7.34 (m, 3H). $^{13}$C NMR (100 MHz, CDCl$_3$) δ 133.9, 131.9, 131.6, 129.0, 128.6, 128.1, 126.2, 126.1, 126.0, 124.9, 122.9, 122.7, 121.8, 95.2, 85.6. HRMS (El) Calcd for C$_{15}$H$_{10}$F$_3$O $[M+H]^+$, 263.0678; found, 263.0685.

2-(phenylethynyl)naphthalene (3t): White solid, mp:106−107 °C (ref 14 105−106 oC). $^1$H NMR (400 MHz, CDCl$_3$) δ 8.52 (d, $J = 8.4$ Hz, 1H), 7.94 − 7.86 (m, 2H), 7.83 (d, $J = 7.2$ Hz, 1H), 7.76−
7.68 (m, 2H), 7.65 (t, \(J = 7.6\) Hz, 1H), 7.58 (t, \(J = 7.2\) Hz, 1H), 7.52 (t, \(J = 7.6\) Hz, 1H), 7.44 (d, \(J = 7.6\) Hz, 3H). \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta 133.3, 133.2, 131.7, 130.4, 128.8, 128.5, 128.4, 128.3, 126.8, 126.5, 126.2, 125.3, 123.5, 120.9, 94.4, 87.6. HRMS (EI) Calcd for C\(_{18}\)H\(_{13}\) [M+H]\(^+\), 229.1012; found, 229.1019.

**4-(phenylethynyl)pyridine (3u):** White solid, mp:95−97 °C (ref 17 94−94.5 °C). \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta 7.57−7.49\) (m, 2H), 7.44 (d, \(J = 8.0\) Hz, 2H), 7.31 (d, \(J = 7.0\) 3H), 7.14 (d, \(J = 8.0\) Hz, 2H), 2.66−2.54 (m, 2H), 1.65−1.54 (m, 2H), 1.31 (dd, \(J = 6.4, 3.2\) Hz, 4H), 0.89 (t, \(J = 6.8\) Hz, 3H). \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta 143.5, 131.6, 131.5, 128.5, 128.3, 128.1, 123.6, 120.5, 89.7, 88.8. HRMS (EI) Calcd for C\(_{13}\)H\(_{10}\)N [M+H]\(^+\), 180.0808; found, 180.0813.

**1,3-bis(phenylethynyl)benzene (3v):** White solid, mp:106−108 °C (ref 2 104−105 °C). \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta 7.73\) (s, 1H), 7.56 (d, \(J = 4.4\) Hz, 2H), 7.54 (d, \(J = 2.0\) Hz, 2H), 7.51 (d, \(J = 1.6\) Hz, 1H), 7.48 (d, \(J = 1.6\) Hz, 1H), 7.37−7.32 (m, 7H). \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta 136.0, 133.1, 132.7, 130.0, 129.9, 129.8, 125.1, 124.5, 91.4, 90.0. HRMS (EI) Calcd for C\(_{22}\)H\(_{15}\) [M+H]\(^+\), 279.1168; found, 279.1160.

**References**

5. Csekei, Marton; Tetrahedron 2007, V64(6), P975-982.
Copies of NMR Spectra

(1) 1,2-bis(4-methoxyphenyl)ethyne (2a)

\[
\begin{align*}
\text{MeO} & \quad \equiv & \quad \equiv \\
& \quad \quad & \quad \quad \\
& \quad \text{OMe}
\end{align*}
\]
(2) 1-methoxy-4-(p-tolylethynyl)benzene (2b)

\[
\text{MeO} - \text{\(\equiv\)} - \text{\(\equiv\)} - \text{\(\equiv\)}
\]
(3) 1-ethyl-4-(((4-methoxyphenyl)ethynyl)benzene (2c)
15

(4) 1-Butyl-4-(4-methoxyphenyl)ethynyl benzene (2d)
MeO

(5) 1-Methoxy-4-((4-nitrophenyl)ethynyl)benzene (2e)
(6) 1-methoxy-4-(m-tolylethynyl)benzene (2f)
(7) 1-methoxy-4-(m-bromoethyl)benzene (2g)
(8) 2-((4-methoxyphenyl)ethynyl)naphthalene (2h)
(9) 2-(4-Methoxyphenyl)benzofuran (2i)
(10) 1-(hex-1-ynyl)-4-methoxybenzene (2j)
(11) 1-(hept-1-ynyl)-4-methoxybenzene (2k)

\[
\text{MeO} \quad \equiv \quad \equiv \quad \equiv \quad \equiv \\
\]
(12) 1-(oct-1-ynyl)-4-methoxybenzene (2l)
(13) 1-(3, 3-Dimethyl-1-butynyl)-4-methoxybenzene (2m):
(14) 1-methyl-4-(phenylethynyl)benzene (3a):
(15) 1-ethyl-4-(phenylethynyl)benzene (2b):
(16) 2-diphenylethyne (3c):
(17) 1-methoxy-4-(phenylethynyl)benzene (3d):
(18) 1-nitro-4-phenylethynylbenzene (3e):
(19) 1-chloro-4-(phenylethynyl)benzene (3f)
(20) 1-(phenylethynyl)-4-(trifluoromethyl)benzene (3g):
(21) 1-(4-(phenylethynyl)phenyl)ethanone (3h):
(22) 1-ethyl-4-(phenylethynyl)benzoate (3i):
(23) 1-(phenylethynyl)-4-(trifluoromethoxy)benzene (3j):
(24) 1-bromo-4-(phenylethynyl)benzene (3k):
(25) 1-methoxy-3-(phenylethynyl)benzene (3l):
(26) 1-methyl-3-(phenylethynyl)benzene (3m):
(27) 1-(phenylethynyl)-3- (trifluoromethyl)benzene (3n):
(28) 1-ido-3-(phenylethynyl)benzene (3o):
(29) 1-methoxy-2-(phenylethynyl)benzene (3p):
(30) 1-methyl-2-(phenylethynyl)benzene (3q):
(31) 1-chloro-2-(phenylethynyl)benzene (3r):
(32) 1-trifluoromethyl-2-(phenylethynyl)benzene (3s):
(33) 2-(phenylethynyl)naphthalene (3t):
(34) 1-pentyl-4-(phenylethynyl)benzene (3u):

\[ \text{N} \]
(3S,3'S)-1,3-bis(phenylethynyl)benzene (3v):