5-2012

Regioselective Synthesis of Tetraalkynylarenes by Consecutive Dual Sonogashira Coupling Reactions of the Bis(triflate) of 4,5-Diiodobenzene-1,2-diol

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Regioselective Synthesis of Tetraalkynylarenes by Consecutive Dual Sonogashira Coupling Reactions of the Bis(triflate) of 4,5-Diiodobenzene-1,2-diol

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Abstract

The regioselective synthesis of nonsymmetric tetraalkynylarenes has been readily achieved through consecutive sets of Sonagashira cross-coupling reactions of the bis(triflate) derivative of 4,5-diiodobenzene-1,2-diol. The initial coupling reactions proceeded with nearly complete selectivity for the reaction at the Ar–I linkages. Subsequent coupling reactions at the Ar–OTf linkages were efficiently conducted. The tetraalkynylarene products are of interest as components of organic molecular materials.

Keywords: Cross-coupling, Regioselectivity, Palladium, Alkynes

Results and Discussion

Diiodo bis(triflate) 1 was readily prepared in three steps from 1,2-dimethoxybenzene as shown in Scheme 2. Electrophilic iodination of 1,2-dimethoxybenzene proceeded in 86% yield.7 Bis(demethylation), followed by disulfonation of the resulting catechol proceeded quantitatively to furnish 1. We used this procedure to prepare up to 20 g of 1, which is stable in the dark at room temperature for months.

The selectivity of Sonagashira coupling reactions of 1 was investigated by using the benzyl ether of 4-pentylnol as a model alkyne (Table 1). [PdCl2(PPh3)2] proved to be an efficient catalyst at a loading of 6 mol-% (Entry 1). Good yields
of the 1,2-bis(alkynyl) product could be obtained at lower catalyst loadings but at the cost of extended reaction times (Entry 4). Complete conversion of the starting material at lower catalyst loadings could be achieved by performing the reaction at higher temperatures (Entry 5), but these conditions resulted in the formation of copious amounts of by-products that were difficult to separate from the desired diyne. Alternative sources of Pd or Pd provided lower conversions and only trace amounts of the product (Entries 8 and 9). A 2:1 ratio of Cu/Pd proved optimal for the transformation. Complete selectivity for the coupling of the aryl iodides was found when 2.3 equiv. of alkyne were used; no appreciable amounts of products resulting from coupling to the triflates were detected. However, performing the reaction in the presence of a large excess (5 equiv.) of alkyne did lead to the formation of significant amounts of inseparable byproducts, which appeared to include the tri- and tetraalkynybenzene (not shown).

The selectivity of the reaction is significant. One might envisage that the introduction of an alkyne in the first Sonogashira coupling might direct the second coupling away from the aryl iodide and towards one of the electrophiles in alkyne cross-coupling reactions. However, the selective Sonogashira coupling of aryl iodides in the presence of aryl triflates has previously been demonstrated. Interestingly, the reaction of 1 with only 1.1 equiv. of (4-methoxyphenyl) ethyne under typical reaction conditions generated the diyne and monoyne in a 1.3:1 ratio in a combined yield of 81% (not shown). The modest preference for dialkynylation could reflect a directing effect of the \textit{ortho}-alkyne or, alternatively, a more facile insertion into the hindered aryliodide due to the diffusion-controlled proximity of the Pd catalyst to the electrophile.

With the optimized reaction conditions in hand, we investigated the scope of the selective cross-coupling reaction of 1 with a variety of alkynes (Table 2). Although most reactions were complete in 3 h, some alkynes required longer times for the complete consumption of the starting material (Entries 2 and 14). The reactions proceeded smoothly with alkynes functionalized with esters (Entry 2), nitriles (Entry 3), silyl ethers (Entry 4), alkyl chlorides (Entry 5), THP ethers (Entry 10), and an acetal (Entry 12). Aromatic alkynes also proved to be excellent coupling partners (Entries 7–9). Coupling reactions with nonpolar alkynes (e.g., heptyne) appeared to proceed to completion (TLC); however, because of the difficulty in completely separating the products from recovered alkyne and nonpolar by-products by silica chromatography, these examples are not reported. Cross-coupling with a tertiary propargyl alcohol proceeded in good yield (Entry 11), whereas reactions with unhindered propargyl ethers (Entries 13 and 14) provided lower yields of the bis(alkynes). Given the frequent application of propargyl alcohols and ethers as nucleophiles in Sonogashira coupling reactions, we are uncertain as to why their use has limitations in this setting.

We next investigated the conditions for displacing both triflates in a second set of Sonogashira coupling reactions (Table 3). By using conditions related to those reported by Powell and Rychnovsky,\textsuperscript{a} diyne 2a was coupled with the TBS ether of 5-hexynol to yield tetrayne 3a in 72% yield (Entry 1). Further modification of the reported conditions did not lead to any notable improvement (data not shown). The scope of the second set of coupling reactions was then investigated (Entries 2–9).

Finally, we compared our new approach directly against an existing methodology for the synthesis of 3i, a target previously prepared in four steps and 11% yield from 1,2-dibromo-4,5-diodobenzene (Scheme 3).\textsuperscript{2b} By using our method, 3i could be prepared from diiododitri fluoride 1 in two steps and 61% yield (or five steps and 53% overall yield from 1,2-dimethoxybenzene).

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**Table 1. Optimization of the alkyne coupling reaction with 1.**\textsuperscript{[a]}

<table>
<thead>
<tr>
<th>Entry</th>
<th>Pd cat. (amount [mol-%])</th>
<th>Alkyne equiv.</th>
<th>Conv. [%]</th>
<th>Yield [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>[PdCl(_2)(PPh(_3))(_2)] (6)</td>
<td>2.3</td>
<td>&gt;99</td>
<td>84</td>
</tr>
<tr>
<td>2</td>
<td>[PdCl(_2)(PPh(_3))(_2)] (3)</td>
<td>2.3</td>
<td>68</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>[PdCl(_2)(PPh(_3))(_2)] (3)</td>
<td>2.5</td>
<td>67</td>
<td>2</td>
</tr>
<tr>
<td>4[b]</td>
<td>[PdCl(_2)(PPh(_3))(_2)] (3)</td>
<td>2.3</td>
<td>&gt;99</td>
<td>70</td>
</tr>
<tr>
<td>5[d]</td>
<td>[PdCl(_2)(PPh(_3))(_2)] (6)</td>
<td>2.1</td>
<td>&gt;95</td>
<td>69</td>
</tr>
<tr>
<td>6</td>
<td>[PdCl(_2)(PPh(_3))(_2)] (6)</td>
<td>2.3</td>
<td>&gt;99</td>
<td>nd</td>
</tr>
<tr>
<td>7</td>
<td>[PdCl(_2)(PPh(_3))(_2)] (6)</td>
<td>2.5</td>
<td>&gt;99</td>
<td>81</td>
</tr>
<tr>
<td>8</td>
<td>[Pd(PPh(_3))(_2)] (6)</td>
<td>2.3</td>
<td>52</td>
<td>trace</td>
</tr>
<tr>
<td>9</td>
<td>[PdCl(_2)(dppe)] (6)</td>
<td>2.3</td>
<td>47</td>
<td>trace</td>
</tr>
</tbody>
</table>

[a] Reagents: 1 (0.4 mmol), CuI/Pd (2:1); nd = not determined. \[b\] Isolated yield. \[c\] Time = 10 h. \[d\] T = 60 °C.

**Table 2. Substrate scope for the selective coupling of 1.**\textsuperscript{[a]}

<table>
<thead>
<tr>
<th>Entry</th>
<th>R</th>
<th>t [h]</th>
<th>Product, yield [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(CH(_3))(_2)OBn</td>
<td>3</td>
<td>2a, 84</td>
</tr>
<tr>
<td>2</td>
<td>(CH(_3))(_2)OBz</td>
<td>5</td>
<td>2b, 71</td>
</tr>
<tr>
<td>3</td>
<td>(CH(_3))CN</td>
<td>3</td>
<td>2c, 78</td>
</tr>
<tr>
<td>4</td>
<td>(CH(_3))OTBS</td>
<td>3</td>
<td>2d, 94</td>
</tr>
<tr>
<td>5</td>
<td>(CH(_3))Cl</td>
<td>3</td>
<td>2e, 76</td>
</tr>
<tr>
<td>6</td>
<td>TIPS</td>
<td>3</td>
<td>2f, 46</td>
</tr>
<tr>
<td>7</td>
<td>4-MeOC(_2)H(_4)</td>
<td>3</td>
<td>2g, 78</td>
</tr>
<tr>
<td>8</td>
<td>2-Py</td>
<td>3</td>
<td>2h, 69</td>
</tr>
<tr>
<td>9</td>
<td>2-Py</td>
<td>3</td>
<td>2h, 84[c]</td>
</tr>
<tr>
<td>10</td>
<td>(CH(_3))O(_2)TP</td>
<td>3</td>
<td>2i, 85</td>
</tr>
<tr>
<td>11</td>
<td>C(CH(_3))(_2)OH</td>
<td>3</td>
<td>2j, 72</td>
</tr>
<tr>
<td>12</td>
<td>CH(_2)(OEt)(_2)</td>
<td>3</td>
<td>2k, 69</td>
</tr>
<tr>
<td>13</td>
<td>CH(_3)OBz</td>
<td>3</td>
<td>2l, 46</td>
</tr>
<tr>
<td>14</td>
<td>CH(_3)Obn</td>
<td>5</td>
<td>2m, 43</td>
</tr>
</tbody>
</table>

[a] Reagents: 1 (0.4 mmol), THF (1 mL). \[b\] Isolated yield. \[c\] On a 3.2 mmol scale.
Table 3. Synthesis of tetraalkynylarenes by dual coupling of dialkynylarenediyl bis(triflates). [a]

<table>
<thead>
<tr>
<th>Entry</th>
<th>R</th>
<th>R’</th>
<th>Product, yield [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(CH₃)₂OBn</td>
<td>(CH₃)₂OTBS</td>
<td>3a, 72</td>
</tr>
<tr>
<td>2</td>
<td>(CH₃)₂OBn</td>
<td>(CH₃)₂OBz</td>
<td>3b, 64</td>
</tr>
<tr>
<td>3</td>
<td>(CH₃)₂OBn</td>
<td>TMS</td>
<td>3c, 64</td>
</tr>
<tr>
<td>4</td>
<td>(CH₃)₂OBn</td>
<td>Ph</td>
<td>3d, 83</td>
</tr>
<tr>
<td>5</td>
<td>(CH₃)₂OBn</td>
<td>4-MeOC₆H₄</td>
<td>3e, 79</td>
</tr>
<tr>
<td>6</td>
<td>(CH₃)₂OBn</td>
<td>4-FC₆H₄</td>
<td>3f, 74</td>
</tr>
<tr>
<td>7[c]</td>
<td>(CH₃)₂OTBS</td>
<td>(CH₃)₂OBz</td>
<td>3g, 68</td>
</tr>
<tr>
<td>8</td>
<td>4-MeOC₆H₄</td>
<td>TMS</td>
<td>3h, 57</td>
</tr>
<tr>
<td>9</td>
<td>2-Py</td>
<td>4-(Bu₂N)C₆H₄</td>
<td>3i, 73</td>
</tr>
</tbody>
</table>

[a] Reagents and conditions: on a 0.25 mmol scale, DMF/TEA (5:1) (1.5 mL), sealed vial. [b] Isolated yield. [c] KI (3 equiv.) used instead of TBAI.

Scheme 3. Comparison of the protocol developed here with an existing methodology.

Conclusions

The selective Sonogashira cross-coupling reaction of 1,2-diiodobenzene-4,5-diyl bis(triflate) proceeds with almost complete selectivity displacing both iodine atoms to furnish a 4,5-bis(alkynyl)benzene-1,2-diyl bis(triflate), which can be subjected to a second set of alkyn coupling reactions to efficiently give nonsymmetric 1,2,4,5-tetraalkynylarenes. Structurally related 1,2-diyl bis(triflates) have been shown to undergo dual Suzuki coupling reactions, which suggests our results could potentially be extended to other transition-metal-catalyzed cross-coupling reactions.

Experimental Section

General: All the reactions were carried out in flame-dried glassware under dry nitrogen with magnetic stirring. Solvents were used as purchased with the exception of THF and CH₂Cl₂, which were distilled from Na/Ph₃CO and CaH₂, respectively. TLC was performed on 0.25 mm hard-layer silica G plates; developed plates were visualized with a UV lamp and/or by staining: vanillin (general stain, after charring), 1% aq. KMnO₄ (for unsaturated compounds), I₂ or phosphomolybdic acid (general stain, after charring). NMR spectra were recorded in CDCl₃ (by using residual CHCl₃; δ = 7.286 ppm) at 300/400/500/600 MHz (¹H) or 75/100/125/150 MHz (¹³C), as indicated. ¹H NMR chemical shifts are reported as δ in ppm as follows: chemical shift [multiplicity, coupling constant(s) in Hz, integration]. ¹³C NMR chemical shifts are reported as δ in ppm. IR spectra were recorded as neat ATR films with selected absorbances reported in wavenumbers (cm⁻¹).

1,2-Diido-4,5-dimethoxybenzene: This compound was prepared according to the procedure of LaCours et al. ³⁷H₂O (0.41 equiv., 25.6 mmol, 5.84 g) and MeOH (36 mL) were added to a flame-dried 100 mL round-bottomed flask equipped with a short air condenser. The mixture was stirred at room temp., and then I₂ (0.8 equiv., 50.2 mmol, 12.76 g) was added. The reaction mixture was stirred vigorously for 10 min, after which 1,2-dimethoxybenzene (1 equiv., 63 mmol, 8.7 g, 8.0 mL) was added in one portion through a syringe. The reaction mixture was heated at 70°C in an oil bath for 5 h, which resulted in the formation of a white solid that made stirring difficult; however, the reaction proceeded even without efficient stirring. The hot solution was poured into dilute aqueous Na₂S₂O₅ (ca. 100 mL), and the mixture was cooled to room temp. The solid collected by filtration through a glass frit was washed quickly with two 30 mL portions of cold MeOH and dried in vacuo to afford 1,2-diido-4,5-dimethoxybenzene (28.07 g, 54 mmol, 86%) as a white solid that was deemed pure by NMR spectroscopy and used without further purification. Rf = 0.49 (20% ethyl acetate/hexane). M.p. 134.5–136.0 °C (ref. ³7134.0 °C). ¹H NMR (600 MHz): δ = 7.25 (s, 2 H), 3.85 (s, 6 H) ppm. ¹³C NMR (150 MHz): δ = 149.6, 121.7, 96.1, 56.2 ppm.

1,2-Dihydroxy-4,5-diiodobenzene: A flame-dried 250 mL round-bottomed flask was charged with 1,2-diido-4,5-dimethoxybenzene (1 equiv., 10 mmol, 3.90 g) and then evacuated/back-filled with nitrogen (3×) before addition of CH₂Cl₂ (70 mL). The solution was cooled to 0 °C, and Br₂ (2.5 equiv., 25 mmol, 25 mL) was added to a 1.0 M solution in CH₂Cl₂ (0.41 equiv., 50.2 mmol, 12.76 g) was added. The reaction mixture was stirred at 0 °C for 4 h and then quenched with H₂O (50 mL). The separated aqueous layer was extracted with Et₂O (2–75 mL). The combined organic layers were dried with MgSO₄, filtered through a pad of silica, and concentrated in vacuo to afford 1,2-dihydroxy-4,5-diiodobenzene (3.61 g, 9.99 mmol, quant.) as an off-white solid that was deemed pure by NMR spectroscopy and used without further purification. Rf = 0.50 (50% ethyl acetate/hexane). M.p. 116.0–116.5 °C. ¹H NMR (400 MHz, [D₆]acetone): δ = 7.25 (s, 2 H), 3.85 (s, 6 H) ppm. ¹³C NMR (150 MHz, [D₆]acetone): δ = 149.6, 121.7, 96.1, 56.2 ppm.

4,5-Diido-1,2-phenylene Bis(trifluoromethanesulfonylate) (1): 1,2-Dihydroxy-4,5-diiodobenzene (1 equiv., 7.85 mmol, 2.84 g), CH₂Cl₂ (55 mL), and pyridine (3 equiv., 39 mmol, 3.10 g, 3.16 mL) were added to a flame-dried 100 mL round-bottomed flask. The solution was cooled to 0 °C, and Tf₂O (2.2 equiv., 17.3 mmol, 4.88 g, 2.91 mL) was added dropwise through a syringe over 10 min. The reaction mixture was stirred for 6 h, while warming to ambient temperature, then cooled to 0 °C, and quenched with H₂O (30 mL). The separated aqueous layer was extracted with CH₂Cl₂ (2×30 mL). The combined organic layers were dried with MgSO₄ and filtered through a tall pad of silica. The pad was washed carefully with CH₂Cl₂ to avoid the elution of impurities, and the filtrate was concentrated in vacuo to afford 1 (4.90 g, 7.82 mmol, quant.) as an off-white solid that was deemed pure by NMR spectroscopy and used without further purification. (Note: For reactions in which small amounts of impurities were observed after filtration, the product could be obtained in...
pure form by column chromatography utilizing 10% ethyl acetate/hexane as the mobile phase. R_f = 0.60 (10% ethyl acetate/hexane). M.p. 46.5–47.7 °C. 1H NMR (400 MHz): δ = 7.24, 7.38, 7.57, 7.60, 7.73 ppm. 13C NMR (100 MHz): δ = 165.5, 126.6, 118.6, 118.5 (q, J_C,F = 315.7 Hz), 13.5 ppm. FTIR: ν = 2941, 1481, 1435, 1381, 1215, 1135, 881, 834, 574 cm⁻¹. HRMS (EI): calcd. for C₂₈H₂₆F₁₀S₈SiNa [M + Na]⁺ 769.0608; found 769.0798.

### 4.5-Bis(6-chlorohex-1-ynyl)-1,2-phenylene Bis(trifluoromethanesulfonate) (2e): Yield: 154 mg, 0.288 mmol, 72%. Mobile phase: step gradient 10–20% ethyl acetate/hexane. R_f = 0.22 (15% ethyl acetate/hexane). 1H NMR (600 MHz): δ = 7.48 (s, 2 H), 2.85 (br, s, 2 H), 1.66 (s, 2 H). M.p. 150 °C; δ = 139.3, 127.5, 125.8, 118.5 (q, J_C,F = 312.0 Hz). 1H NMR (600 MHz): δ = 7.24, 7.38, 7.57, 7.60, 7.73 ppm. 13C NMR (150 MHz): δ = 165.5, 126.6, 118.6, 118.5 (q, J_C,F = 315.7 Hz), 13.5 ppm. FTIR: ν = 2941, 1481, 1435, 1381, 1215, 1135, 881, 834, 574 cm⁻¹. HRMS (EI): calcd. for C₂₈H₂₆F₁₀S₈SiNa [M + Na]⁺ 769.0608; found 769.0798.

### 4.5-Bis(3,5-diethoxypropyl-1-ynyl)-1,2-phenylene Bis(trifluoromethanesulfonate) (2k): Yield: 172 mg, 0.276 mmol, 69%. Mobile phase: step gradient hexane to 5% ethyl acetate/hexane. R_f = 0.60 (10% ethyl acetate/hexane). M.p. 46.5–47.7 °C. 1H NMR (400 MHz): δ = 7.24, 7.38, 7.57, 7.60, 7.73 ppm. 13C NMR (100 MHz): δ = 165.5, 126.6, 118.6, 118.5 (q, J_C,F = 315.7 Hz), 13.5 ppm. FTIR: ν = 2941, 1481, 1435, 1381, 1215, 1135, 881, 834, 574 cm⁻¹. HRMS (EI): calcd. for C₂₈H₂₆F₁₀S₈SiNa [M + Na]⁺ 769.0608; found 769.0798.

### 4.5-Bis(4-hydroxy-3-methylbut-1-ynyl)-1,2-phenylene Bis(trifluoromethanesulfonate) (2l): Yield: 230 mg, 0.340 mmol, 85%. Mobile phase: step gradient 10–20% ethyl acetate/hexane. R_f = 0.22 (15% ethyl acetate/hexane). M.p. 150 °C; δ = 139.3, 127.5, 125.8, 118.5 (q, J_C,F = 312.0 Hz). 1H NMR (600 MHz): δ = 7.24, 7.38, 7.57, 7.60, 7.73 ppm. 13C NMR (150 MHz): δ = 165.5, 126.6, 118.6, 118.5 (q, J_C,F = 315.7 Hz), 13.5 ppm. FTIR: ν = 2941, 1481, 1435, 1381, 1215, 1135, 881, 834, 574 cm⁻¹. HRMS (EI): calcd. for C₂₈H₂₆F₁₀S₈SiNa [M + Na]⁺ 769.0608; found 769.0798.
etate/hexane. $R_f = 0.22$ (5% ethyl acetate/hexane).

1H NMR (600 MHz): $\delta = 7.58$ (s, 2 H), 5.52 (s, 2 H), 3.79–3.9 (4 H), 3.64–3.74 (4 H), 1.29 (t, $J = 7.2$ Hz, 12 H) ppm.

13C NMR (150 MHz): $\delta = 139.8, 129.0, 126.7, 118.5$ (q, $J_{CF} = 320.9$ Hz), 92.9, 91.5, 80.3, 61.3, 15.1 ppm. FTIR: $\nu \approx 3675, 2979, 2901, 1490, 1435, 1248, 1211, 1178, 1135, 1076, 1050, 868, 814$ cm$^{-1}$. HRMS (ESI): calcd. for C$_{22}$H$_{36}$O$_{5}$Si$_{2}$Na $[M + Na]^+$ 694.0613; found 694.0610.

3.3'-[4,4'-Bis(trifluoromethanesulfonfonyl)-1,2-phenyleneidiprop-2-ynyl]Dibenzoate (2f): Yield: 127 mg, 0.184 mmol, 46%. M.p. 78.4–79.5 °C. Mobile phase: step gradient hexane to 8% ethyl acetate/hexane.

Yield: 127 mg, 0.172 mmol, 46%. Mobile phase: step gradient 5-10% ethyl acetate/hexane. $R_f = 0.32$ (10% ethyl acetate/hexane).

1H NMR (600 MHz): $\delta = 7.57–7.63$ (6 H), 7.34–7.42 (14 H), 2.79–7.34 (2 H), 4.58 (s, 4 H), 3.69 (t, $J = 6.1$ Hz, 4 H), 2.64 (t, $J = 7.0$ Hz, 4 H), 1.97 (quint, $J = 6.6$ Hz, 4 H) ppm. 13C NMR (150 MHz): $\delta = 138.5, 131.5, 131.7, 128.7, 128.5, 128.4, 126.7, 126.1, 126.9, 124.6, 123.1, 95.6, 94.9, 87.6, 79.2, 73.0, 68.7, 28.9, 16.6 ppm. FTIR: $\nu \approx 2856, 2224, 1650, 1501, 1413, 1364, 1342, 1136, 1072, 899, 754, 734, 688$ cm$^{-1}$. HRMS (ESI): calcd. for C$_{46}$H$_{40}$O$_{3}$Si$_{2}$Na $[M + Na]^+$ 645.2770; found 645.2759.

5,5'-[4,5-Bis(butylbutyldimethylsilyloxy)hex-1-ynyl]-1,2-phenyleneidiprop-4-ynyl Dibenzoate (3b): Yield: 127 mg, 0.185 mmol, 74%. Mobile phase: 8% ethyl acetate/hexane. $R_f = 0.36$ (10% ethyl acetate/hexane).

1H NMR (600 MHz): $\delta = 7.52–7.78$ (6 H), 7.34–7.42 (8 H), 7.28–7.38 (2 H), 6.88–6.93 (4 H), 4.56 (s, 4 H), 3.86 (t, $J = 6.1$ Hz, 4 H), 2.62 (t, $J = 7.0$ Hz, 4 H), 1.95 (quint, $J = 6.6$ Hz, 4 H) ppm. 13C NMR (150 MHz): $\delta = 152.9, 138.5, 134.8, 133.2, 128.4, 127.6, 127.59, 125.5, 124.7, 113.5, 114.1, 95.2, 94.9, 86.6, 79.3, 73.3, 68.7, 53.8, 28.9, 16.6 ppm. FTIR: $\nu \approx 2923, 2857, 2209, 1604, 1568, 1511, 1289, 1246, 1172, 1141, 1042, 1077, 899, 629, 734, 696$ cm$^{-1}$.

HRMS (ESI): calcd. for C$_{66}$H$_{70}$O$_{5}$Si$_{2}$Na $[M + Na]^+$ 705.2981; found 705.2974.

5,5'-[4,5-Bis(4-fluorophenyl)diprop-2-ynyl]Dibenzoate (3g): Yield: 149 mg, 0.170 mmol, 68%. Mobile phase: 8% ethyl acetate/hexane. $R_f = 0.26$ (10% ethyl acetate/hexane).

1H NMR (600 MHz): $\delta = 8.03–8.08$ (4 H), 7.34–7.42 (8 H), 7.28–7.38 (2 H), 5.72–5.79 (2 H), 4.57 (s, 4 H), 3.68 (t, $J = 6.1$ Hz, 4 H), 2.63 (t, $J = 7.0$ Hz, 4 H), 1.96 (quint, $J = 6.6$ Hz, 4 H) ppm. 13C NMR (150 MHz): $\delta = 162.8$ (d, $J_{CF} = 250.5$ Hz), 138.5, 135.0, 133.5 (d, $J_{CF} = 8.6$ Hz), 128.4, 127.61, 127.60, 126.0, 124.3, 119.2 (d, $J_{CF} = 4.4$ Hz), 115.8 (d, $J_{CF} = 22.5$ Hz), 95.7, 93.7, 87.3, 79.1, 73.0, 68.7, 28.9, 16.6 ppm. FTIR: $\nu \approx 2923, 2856, 2225, 1600, 1567, 1070, 1227, 1155, 1102, 899, 833, 792, 734, 696$ cm$^{-1}$.

HRMS (ESI): calcd. for C$_{66}$H$_{70}$O$_{5}$Si$_{2}$Na $[M + Na]^+$ 681.2581; found 681.2567.
bile phase: 4% ethyl acetate/hexane. $R_f = 0.38$ (10% ethyl acetate/hexane). $^1$H NMR (600 MHz): $\delta = 7.66$ (s, 2 H), 7.47–7.55 (4 H), 6.86–6.93 (4 H), 3.85 (s, 6 H), 0.31 (s, 18 H). 13C NMR (150 MHz): $\delta = 160.0, 135.2, 133.2, 125.6, 124.8, 115.1, 114.1, 102.4, 100.4, 95.7, 86.4, 55.3, 0.0$ ppm. FTIR: $\nu = 2959, 2213, 2156, 1605, 1513, 1290, 1167, 1031, 828$ cm$^{-1}$. HRMS (EI): calcd. for $\text{C}_{34}\text{H}_{32}\text{O}_{2}\text{Si}_2$ $[M]$ $^+$ 530.2097; found 530.2093.

1,2-Bis[4-(dibutylamino)phenyl]ethynyl]-4,5-bis[2-(2-pyridyl)ethynyl]benzene (3i): Yield: 134 mg, 0.183 mmol, 73%. Mobile phase: 35% ethyl acetate/hexane. $R_f = 0.35$ (40% ethyl acetate/hexane). $^1$H NMR (600 MHz): $\delta = 8.64–8.70$ (2 H), 7.78 (s, 2 H), 7.73 (d, $J = 7.6$ Hz, 2 H), 7.67 (td, $J = 7.8, 1.9$ Hz, 2 H), 7.45 (d, $J = 8.7$ Hz, 2 H), 7.23–7.28 (2 H), 6.61 (d, $J = 8.7$ Hz, 4 H), 3.32 (t, $J = 7.9$ Hz, 8 H), 1.61 (quint, $J = 7.8$ Hz, 8 H), 1.39 (sext, $J = 7.6$ Hz, 8 H), 0.99 (t, $J = 7.3$ Hz, 12 H). 13C NMR (150 MHz): $\delta = 150.1, 148.3, 143.5, 136.1, 134.8, 133.3, 127.8, 126.7, 123.4, 122.9, 111.2, 108.5, 98.0, 93.9, 87.4, 86.0, 50.7, 29.4, 20.3, 14.0$ ppm.

Supporting Information

$^1$H and $^{13}$C NMR spectra for all compounds are presented following the References.

Acknowledgments — We are grateful for financial support from the National Science Foundation (NSF) (EPS 1004094). Preliminary experiments were conducted by Mitch Trauernicht.

References


SUPPORTING INFORMATION

DOI: 10.1002/ejoc.201200079
Title: Regioselective Synthesis of Tetraalkynylarenes by Consecutive Dual Sonogashira Coupling Reactions of the Bis(triflate) of 4,5-Diiodobenzene-1,2-diol
Author(s): Thomas J. Fisher and Patrick H. Dussault*
$^1$H and $^{13}$C Spectra:
1,2-diodo-4,5-dimethoxybenzene
1,2-dihydroxy-4,5-dimethoxybenzene
4,5-Diiodo-1,2-phenylene bistri fluoromethanesulfonate (1)
4,5-Bis(5-benzyloxypent-1-yn-1-yl)-1,2-phenylene bistriflate (2a)
4,5-Bis(trifluoromethylsulfonyloxy)-1,2-phenylene)-bis(pent-4-yne-1-ol-4-yl, benzoate ester) (2b)
4,5-Bis(hexanenitrile-6-yl)-1,2-phenylene bistriflate (2c)
4,5-Bis(6-(tert-butyldimethylsiloxy)hex-1-yn-1-yl)-1,2-phenylene bistriflate (2d)
4,5-Bis(2-methyl-3-butyn-1-ol-4-yl)-1,2-phenylene bistriflate (2e)
4,5-Bis(2-(4-methoxyphenyl)ethynyl)-1,2-phenylene bistriflate (2f)
4,5-Bis(2-(pyridin-2-yl)ethynyl)-1,2-phenylene bistriflate (2g)
4,5-Bis(2-((tetrahydro-2H-pyran-2-yloxy)but-1-yn-1-yl)-1,2-phenylene bistriflate (2h)
4,5-Bis(2-methyl-3-butyn-1-ol-4-yl)-1,2-phenylene bistriflate (2i)
4,5-Bis(2-trimethylsilylethynyl)-1,2-phenylene bistriflate (2j)
4,5-Bis(2-phenylethynyl)-1,2-phenylene bistriflate (2k)
(4,5-Bis(trifluoromethylsulfonyloxy)-1,2-phenylene)bis(prop-2-yne-1-ol-3-yl, benzoate ester) (2l)
4,5-Bis(3-benzyloxyprop-1-yn-1-yl)-1,2-phenylene bistriflate (2m)
4,5-Bis(5-benzyloxyprop-1-yn-1-yl)-1,2-phenylene bis (6-tert-butyldimethylsilyloxyhex-1-yn-1-yl) (3a)
4,5-Bis(5-benzyloxyprop-1-yn-1-yl)-1,2-phenylene-bis(pent-4-yne-1-ol-5-yl, benzoate ester) (3b)
4,5-Bis(5-benzyloxyprop-1-yn-1-yl)-1,2-phenylene bis(2-trimethylsilylethyn-1-yl) (3c)
4,5-Bis(5-benzyloxyprop-1-yn-1-yl)-1,2-phenylene bis(2-phenylethyn-1-yl) (3d)
4,5-Bis(5-benzyloxyprop-1-yn-1-yl)-1,2-phenylene) bis(2-(4-methoxyphenyl) ethyn-1-yl) (3e)
4,4'-(4,5-Bis(5-benzyloxypent-1-yn-1-yl)-1,2-phenylene)bis-2-(4-fluorophenyl)ethyn-1-yl (3f)
(4,5-Bis(6-tert-butyldimethylsilyloxyhex-1-yn-1-yl)-1,2-phenylene)bis(pent-4-yne-1-ol-5-yl, benzoate ester) (3g)
4,5-Bis(2-(4-methoxyphenyl)ethynyl-1-yl)-1,2-phenylene) bis (2-trimethylsilylethynyl-1-yl) (3h)
4,5-Bis(2-(4-pyridyl)ethynyl-1,2-phenylene)bis-2-(4-(N,N'-dibutylanilino)ethyn-1-yl (3i)