

Electronic Supporting Information

Fast copper-, ligand- and solvent-free Sonogashira coupling in a ball mill

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General information:

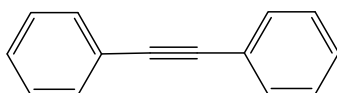
All chemicals were purchased from Sigma Aldrich or Alfa Aesar and were used as received. Reactions were accomplished in a Fritsch “Pulverisette 7 classic line” planetary ball mill using 45 ml grinding beakers (agate, zircon oxide) and milling balls (six pieces × 15 mm in diameter, agate or zircon oxide). GC-FID measurements were performed on a HP-6890 GC, GC-MS measurements were done on a Agilent Technologies GC 6890N with MS detector 5973 [Conditions GC-FID: HP 5, 30 m × 0.32 mm × 0.25 μm, H₂ – 10 psi, program: 70 °C (hold for 3 min), 15 K min⁻¹ up to 280 °C (hold for 10 min), injector temperature: 280 °C, detector temperature: 300 °C. Conditions GC-MSD: HP 5, 30 m × 0.32 mm × 0.25 μm, He – 10 psi, program: 70 °C (hold for 3 min), 15 K min⁻¹ up to 280 °C (hold for 7 min), injector temperature: 280 °C, detector: EI]. NMR spectra were recorded with a Bruker Avance 200 MHz system at room temperature in Chloroform-²H₃ (CDCl₃) as solvent.

Reaction Protocol:

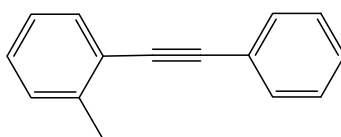
General procedure for the Sonogashira reaction in planetary ball mill: The grinding beakers were filled with the milling balls, SiO₂ (5 g), the acetylene compound (2.5 mmol), DABCO (2.5 mmol, 280 mg), the aryl halide (2 mmol) and Pd(OAc)₂ (5 mol%, 25 mg) were added in the given order. Milling was accomplished at 800 rpm for 20 min. After cooling to room temperature, the crude products were extracted on a frit with a thin silica layer using

chloroform (3 × 10 ml). The solvent was evaporated in vacuum, the crude products were dried and analyzed by GC-FID and GC-MS. Analytical samples for NMR investigation were isolated by column chromatography using n-hexane/toluene mixtures. Products were identified according to literature data.

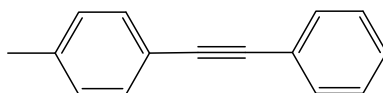
NMR data of Sonogashira coupling products:



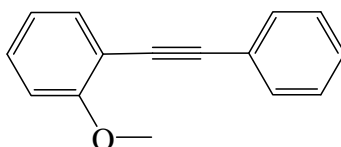
Diphenylethyne (3a):^[1] ¹H-NMR (200 MHz, CDCl₃): δ = 7.61-7.53 (4 H, m), 7.41-7.31 ppm (6 H, m); ¹³C-NMR (50 MHz, CDCl₃): δ = 131.45, 128.21, 128.11, 123.15, 89.44 ppm; GC-MS: m / z = 178 (100%).



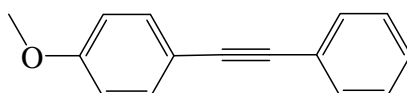
1-Methyl-2-(phenylethynyl)benzene (3b):^[1] ¹H-NMR (200 MHz, CDCl₃): δ = 7.59-7.48 (3 H, m), 7.39-7.32 (3 H, m), 7.26-7.16 (3 H, m), 2.53 ppm (3 H, s); ¹³C-NMR (50 MHz, CDCl₃): δ = 140.15, 131.82, 131.48, 129.44, 128.32, 128.28, 128.14, 125.55, 123.54, 123.01, 93.32, 88.32, 20.70 ppm; GC-MS: m / z = 192 (100%).



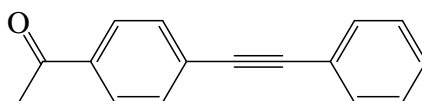
1-Methyl-4-(phenylethynyl)benzene (3c, 3g):^[1] ¹H-NMR (200 MHz, CDCl₃): δ = 7.77-7.69 (2 H, m), 7.64 (2 H, d, *J* = 8.2 Hz), 7.52-7.42 (3 H, m), 7.29 (2 H, d, *J* = 8.1 Hz), 2.49 ppm (3 H, s); ¹³C-NMR (50 MHz, CDCl₃): δ = 138.14, 131.38, 128.99, 128.17, 127.92, 126.24, 123.38, 120.11, 89.60, 88.75, 21.28 ppm; GC-MS: m / z = 192 (100%).



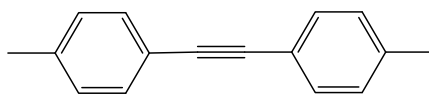
1-Methoxy-2-(phenylethynyl)benzene (3d):^[1] ¹H-NMR (200 MHz, CDCl₃): δ = 7.61-7.56 (2 H, m), 7.53 (1 H, dd, J = 7.5, 1.7 Hz), 7.39-7.26 (4 H, m), 7.00-6.85 (2 H, m), 3.90 ppm (3 H, s); ¹³C-NMR (50 MHz, CDCl₃): δ = 159.89, 133.48, 131.57, 129.69, 128.17, 128.02, 123.53, 120.41, 112.41, 110.68, 93.37, 85.73, 55.72 ppm; GC-MS: m/z = 208 (100%).



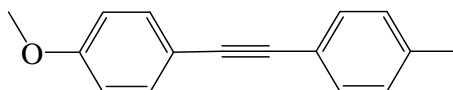
1-Methoxy-4-(phenylethynyl)benzene (3e):^[1] ¹H-NMR (200 MHz, CDCl₃): δ = 7.58-7.46 (4 H, m), 7.39-7.29 (3 H, m), 6.89 (2 H, d, J = 8.7 Hz), 3.80 ppm (3 H, s); ¹³C-NMR (50 MHz, CDCl₃): δ = 159.56, 132.97, 131.37, 128.23, 127.85, 123.55, 115.30, 113.94, 89.38, 88.05, 55.14 ppm; GC-MS: m/z = 208 (100%).



1-Acetyl-4-(phenylethynyl)benzene (3f):^[2] ¹H-NMR (200 MHz, CDCl₃): δ = 7.83 (2 H, d, J = 8.2 Hz), 7.55-7.44 (4 H, m), 7.33-7.23 (3 H, m), 2.47 (3 H, s); ¹³C-NMR (50 MHz, CDCl₃): δ = 196.75, 135.84, 131.44, 131.35, 128.52, 128.16, 127.94, 127.75, 122.34, 92.47, 88.47, 26.16 ppm; GC-MS: m/z = 220 (100%).

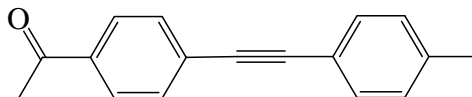


1,2-Di-*p*-tolylethyne (3h):^[2] ¹H-NMR (200 MHz, CDCl₃): δ = 7.49 (4 H, d, J = 8.1 Hz), 7.22 (4 H, d, J = 7.7 Hz), 2.43 ppm (6 H, s); ¹³C-NMR (50 MHz, CDCl₃): δ = 138.04, 137.14, 129.01, 120.38, 88.90, 21.38 ppm; GC-MS: m/z = 206 (100%).

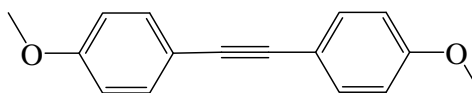


1-Methyl-4-(4'-methoxy-phenylethynyl)benzene (3j):^[2] ¹H-NMR (200 MHz, CDCl₃): δ = 7.50-7.36 (4 H, m), 7.14 (2 H, d, J = 8.0 Hz), 7.18-7.09 (2 H, m), 6.87 (2 H, d, J = 9.0 Hz),

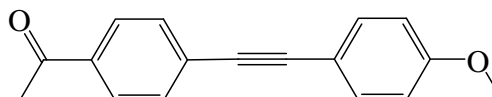
3.81 (3 H, s), 2.36 ppm (3 H, s); ^{13}C -NMR (50 MHz, CDCl_3): $\delta = 159.48, 137.97, 132.94, 131.13, 129.05, 120.502, 115.60, 113.95, 88.64, 88.18, 55.24, 21.44$ ppm; GC-MS: $m/z = 222$ (100%).



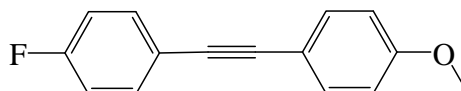
1-Acetyl-4-(p-tolyl-ethynyl)benzene (3k):^[4] ^1H -NMR (200 MHz, CDCl_3): $\delta = 7.85$ (2 H, d, $J = 8.4$ Hz), 7.53 (2 H, d, $J = 8.4$ Hz), 7.41 (2 H, d, $J = 8.0$ Hz), 7.10 (2 H, d, $J = 8.0$ Hz), 2.49 (3 H, s), 2.31 ppm (3 H, s); ^{13}C -NMR (50 MHz, CDCl_3): $\delta = 196.62, 138.65, 137.44, 135.63, 131.32, 131.21, 128.90, 127.88, 119.26, 92.77, 87.89, 26.08, 21.15$ ppm; GC-MS: $m/z = 234$ (100%).



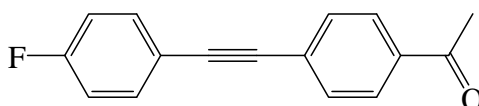
1,2-bis(p-Methoxyphenyl)ethyne (3l):^[5] ^1H -NMR (200 MHz, CDCl_3): $\delta = 7.49$ (4 H, d, $J = 8.1$ Hz), 7.22 (4 H, d, $J = 7.7$ Hz), 2.43 ppm (6 H, s); ^{13}C -NMR (50 MHz, CDCl_3): $\delta = 138.04, 137.14, 129.01, 120.38, 88.90, 21.38$ ppm; GC-MS: $m/z = 238$ (100%).



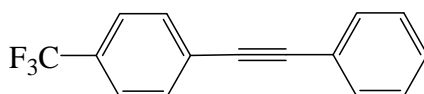
1-Acetyl-4-(4'-methoxy-phenylethynyl)benzene (3m):^[5] ^1H -NMR (200 MHz, CDCl_3): $\delta = 7.83$ (2 H, d, $J = 8.2$ Hz), 7.49 (2 H, d, $J = 8.5$ Hz), 7.41 (2 H, d, $J = 8.7$ Hz), 6.80 (2 H, d, $J = 8.7$ Hz), 3.72 (3 H, s), 2.49 ppm (3 H, s); ^{13}C -NMR (50 MHz, CDCl_3): $\delta = 196.96, 159.85, 135.62, 133.06, 131.21, 128.31, 128.02, 114.44, 113.91, 92.83, 87.39, 55.01, 26.25$ ppm; GC-MS: $m/z = 206$ (100%); GC-MS: $m/z = 250$ (100%).



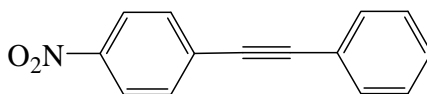
1-Fluoro-4-(4'-methoxy-phenylethynyl)benzene (3n):^[6] ^1H -NMR (200 MHz, CDCl_3): $\delta = 7.53$ - 7.41 (4 H, m), 7.01 (2 H, t, $J = 8.8$ Hz), 6.86 (2 H, d, $J = 8.9$ Hz), 3.81 ppm (3 H, s); ^{13}C -NMR (50 MHz, CDCl_3): $\delta = 164.42, 159.47, 159.33, 132.99, 132.82, 132.63, 119.39, 119.32, 115.41, 114.98, 114.84, 113.70, 88.67, 86.62, 54.91$ ppm; GC-MS: $m/z = 226$ (100%).



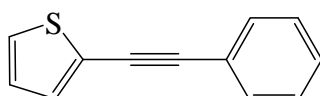
1-Acetyl-4-(4'-fluorophenylethynyl)benzene (3o):^[6] ¹H-NMR (200 MHz, CDCl₃): δ = 7.86 (2 H, d, *J* = 8.5 Hz), 7.57-7.40 (4 H, m), 6.99 (2 H, t, *J* = 8.8 Hz), 2.52 ppm (3 H, s); ¹³C-NMR (50 MHz, CDCl₃): δ = 196.87, 165.06, 160.08, 136.05, 133.58, 133.42, 131.41, 128.07, 118.64, 118.57, 115.79, 115.35, 91.43, 88.23, 26.25 ppm; GC-MS: *m/z* = 238 (100%).



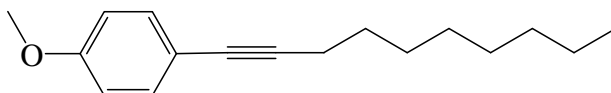
1-Trifluoromethyl-4-(phenylethynyl)benzene (3p):^[7] ¹H-NMR (200 MHz, CDCl₃): δ = 7.61-7.57 (4 H, m), 7.56-7.50 (3 H, m), 7.29 ppm (2 H, t, *J* = 3.2 Hz); ¹³C-NMR (50 MHz, CDCl₃): δ = 131.4, 129.88, 129.22, 128.46, 128.07, 126.77, 124.93, 124.88, 122.22, 91.39, 87.59 ppm; GC-MS: *m/z* = 192 (100%).



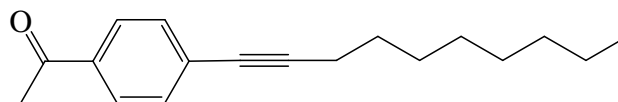
1-Nitro-4-(phenylethynyl)benzene (3q):^[8] ¹H-NMR (200 MHz, CDCl₃): δ = 8.15 (2 H, d, *J* = 8.9 Hz), 7.61 (2 H, d, *J* = 8.3 Hz), 7.54-7.49 (3 H, m), 7.38-7.33 ppm (2 H, m); ¹³C-NMR (50 MHz, CDCl₃): δ = 146.78, 132.15, 131.74, 130.10, 128.91, 128.05, 123.47, 121.88, 94.45, 87.27 ppm; GC-MS: *m/z* = 223 (100%).



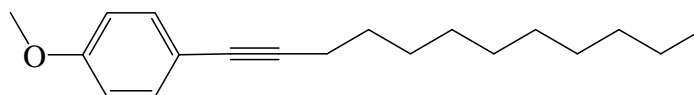
2-Phenylethynylthiophene (5):^[3] ¹H-NMR (200 MHz, CDCl₃): δ = 7.58-7.50 (2 H, m), 7.39-7.25 (5 H, m), 7.04-6.98 ppm (1 H, m); ¹³C-NMR (50 MHz, CDCl₃): δ = 132.46, 131.85, 131.37, 128.33, 127.20, 127.05, 123.30, 122.89, 93.03, 82.62 ppm; GC-MS: *m/z* = 184 (100%).



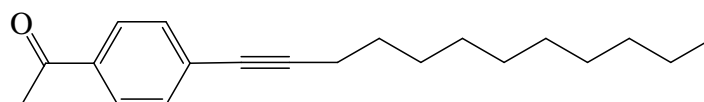
1-(4-Methoxyphenyl)-dec-1-yne (7a): ^{13}C -NMR (200 MHz, CDCl_3): $\delta = 7.31$ (2 H, d, $J = 8.8$ Hz), 6.79 (2 H, d, $J = 8.8$ Hz), 3.78 (3 H, s), 2.36 (2 H, t, $J = 6.9$ Hz), 1.68 - 1.16 (12 H, m), 0.87 (3 H, t, $J = 6.5$ Hz); ^{13}C -NMR (50 MHz, CDCl_3): $\delta = 158.96, 132.82, 116.29, 113.77, 88.80, 80.22, 55.22, 31.83, 29.18, 29.12, 28.93, 28.87, 22.64, 19.34, 14.07$ ppm; GC-MS: $m/z = 244$ (100%).



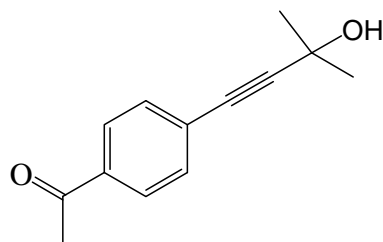
1-(4-Acetylphenyl)-dec-1-yne (7b): ^{13}C -NMR (200 MHz, CDCl_3): $\delta = 7.73$ (2 H, d, $J = 8.1$ Hz), 7.31 (2 H, d, $J = 8.2$ Hz), 2.42 (3 H, s), 2.30 (2 H, t, $J = 6.9$ Hz), 1.58 - 1.04 (12 H, m), 0.78 (3 H, t, $J = 6.6$ Hz); ^{13}C -NMR (50 MHz, CDCl_3): $\delta = 196.41, 135.33, 131.26, 128.85, 127.78, 93.95, 79.89, 31.57, 28.84, 28.67, 28.33, 26.02, 22.38, 19.22, 13.78$ ppm; GC-MS: $m/z = 256$ (100%).



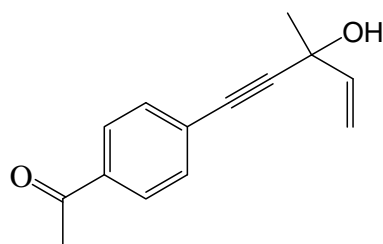
1-(4-Methoxyphenyl)-dodec-1-yne (7c): ^{19}F -NMR (200 MHz, CDCl_3): $\delta = 7.33$ (2 H, d, $J = 8.8$ Hz), 6.79 (2 H, d, $J = 8.8$ Hz), 3.76 (3 H, s), 2.38 (2 H, t, $J = 6.8$ Hz), 1.71 - 1.16 (16 H, m), 0.90 (3 H, t, $J = 6.6$ Hz); ^{13}C -NMR (50 MHz, CDCl_3): $\delta = 158.89, 132.71, 116.31, 113.77, 88.53, 80.24, 54.96, 31.88, 29.56, 29.31, 29.15, 28.88, 22.64, 19.34, 14.02$ ppm; GC-MS: $m/z = 272$ (100%).



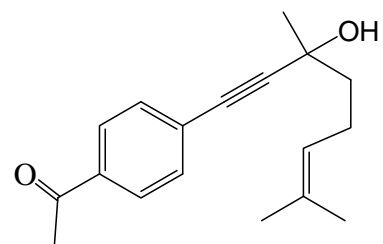
1-(4-Acetylphenyl)-dodec-1-yne (7d): ^1H -NMR (200 MHz, CDCl_3): $\delta = 7.73$ (2 H, d, $J = 8.2$ Hz), 7.32 (2 H, d, $J = 8.3$ Hz), 2.42 (3 H, s), 2.29 (2 H, t, $J = 6.9$ Hz), 1.59 - 0.98 (16 H, m), 0.78 (3 H, t, $J = 6.7$ Hz); ^{13}C -NMR (50 MHz, CDCl_3): $\delta = 196.46, 135.37, 131.31, 128.90, 127.82, 93.99, 79.93, 31.69, 29.37, 29.11, 28.93, 28.72, 28.38, 26.07, 22.45, 19.27, 13.84$ ppm; GC-MS: $m/z = 284$ (100%).



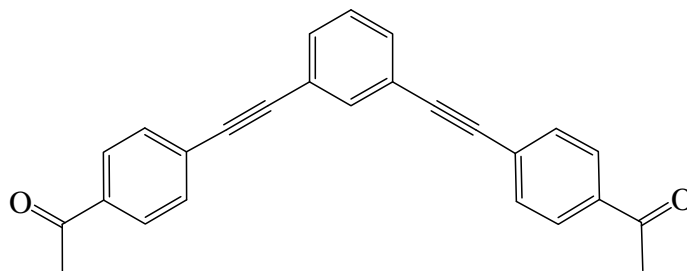
4-(4-Acetylphenyl)-2-methylbut-3-yn-2-ol (9a): 101 $^1\text{H-NMR}$ (200 MHz, CDCl_3): δ = 7.83 (2 H, d, J = 8.3 Hz), 7.43 (2 H, d, J = 8.4 Hz), 2.53 (3 H, s), 2.43 (1 H, bs), 1.61 ppm (6 H, s); $^{13}\text{C-NMR}$ (50 MHz, CDCl_3): δ = 197.10, 136.33, 131.56, 128.35, 127.64, 93.95, 83.54, 68.81, 30.46, 26.53 ppm; GC-MS: m/z = 202 (100%).



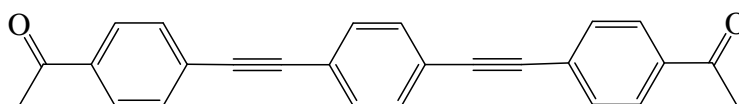
5-(4-Acetylphenyl)-3-methyl-pent-1-en-4-yn-3-ol (9b): $^1\text{H-NMR}$ (200 MHz, CDCl_3): δ = 7.83 (2 H, d, J = 8.3 Hz), 7.44 (2 H, d, J = 8.5 Hz), 6.03 (1 H, dd, J = 10.2 Hz, J = 17.1 Hz), 5.53 (1 H, dd, J = 0.9 Hz, J = 17.1 Hz), 5.13 (1 H, dd, J = 0.9 Hz, J = 10.2 Hz), 2.78 (1 H, bs), 2.54 (3 H, s), 1.63 ppm (3 H, s); $^{13}\text{C-NMR}$ (50 MHz, CDCl_3): δ = 197.41, 141.64, 136.22, 131.68, 128.09, 127.48, 113.76, 94.36, 83.70, 68.47, 29.90, 26.49 ppm; GC-MS: m/z = 214 (100%).



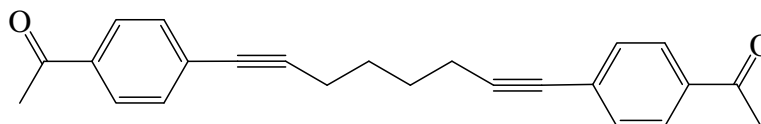
1-(4-Acetylphenyl)-3,7-dimethyl-oct-6-en-1-yn-3-ol (9c): $^1\text{H-NMR}$ (200 MHz, CDCl_3): δ = 7.83 (2 H, d, J = 8.3 Hz), 7.43 (2 H, d, J = 8.3 Hz), 5.16 (1 H, t, J = 7.2 Hz), 2.54 (3 H, s), 2.45 (1 H, bs), 2.39-2.08 (2 H, m), 1.76 (2 H, t, J = 7.5 Hz), 1.65 (3 H, s), 1.61 (3 H, s), 1.54 ppm (3 H, s); $^{13}\text{C-NMR}$ (50 MHz, CDCl_3): δ = 197.30, 136.14, 132.49, 131.66, 128.10, 127.71, 123.67, 96.29, 82.66, 68.71, 43.31, 29.68, 26.47, 25.62, 23.69 ppm; GC-MS: m/z = 270 (100%).



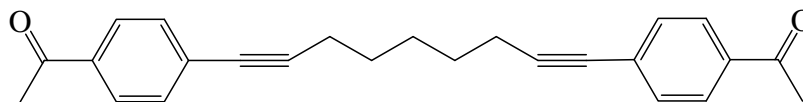
1,3-(4-Acetylphenyl)benzene (11a): $^1\text{H-NMR}$ (200 MHz, CDCl_3): $\delta = 7.92$ (4 H, d, $J = 8.6$ Hz), 7.74-7.69 (1 H, m), 7.58 (4 H, d, $J = 8.6$ Hz), 7.54-7.46 (2 H, m), 7.34 (1 H, t, $J = 7.7$ Hz), 2.59 ppm (6 H, s); $^{13}\text{C-NMR}$ (50 MHz, CDCl_3): $\delta = 197.24$, 136.44, 134.83, 131.86, 131.76, 128.67, 128.30, 127.90, 123.20, 91.57, 89.35, 26.61 ppm.



1,4-(4-Acetylphenyl)benzene (11b): $^1\text{H-NMR}$ (200 MHz, CDCl_3): $\delta = 7.94$ (4 H, d, $J = 8.5$ Hz), 7.60 (4 H, d, $J = 8.4$ Hz), 7.53 (4 H, s), 2.60 ppm (6 H, s); $^{13}\text{C-NMR}$ (50 MHz, CDCl_3): $\delta = 197.25$, 136.50, 132.53, 131.75, 129.55, 128.32, 123.06, 91.18, 88.78, 26.62 ppm.



1,8-(4-Acetylphenyl)oct-1,7-diyne (11c): $^1\text{H-NMR}$ (200 MHz, CDCl_3): $\delta = 7.83$ (4 H, d, $J = 8.5$ Hz), 7.42 (4 H, d, $J = 8.5$ Hz), 2.54 (6 H, s), 2.48 (4 H, t, $J = 6.5$ Hz), 1.77 ppm (4 H, q, $J = 3.2$ Hz); $^{13}\text{C-NMR}$ (50 MHz, CDCl_3): $\delta = 197.27$, 135.74, 131.60, 128.88, 128.12, 93.52, 80.48, 27.64, 26.50, 19.08 ppm.



1,9-(4-Acetylphenyl)non-1,8-diyne (11d): $^1\text{H-NMR}$ (200 MHz, CDCl_3): $\delta = 7.80$ (4 H, d, $J = 8.3$ Hz), 7.40 (4 H, d, $J = 8.3$ Hz), 2.54 (6 H, s), 2.45 (4 H, t, $J = 6.1$ Hz), 1.71-1.58 (6 H, m); $^{13}\text{C-NMR}$ (50 MHz, CDCl_3): $\delta = 196.96$, 135.36, 131.26, 128.60, 127.77, 93.58, 80.08, 27.67, 27.62, 26.17, 19.05 ppm.

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