

Synthesis and characterization of γ -Fe₂O₃@SiO₂-(CH₂)₃-PDTC-Pd magnetic nanoparticles: new and highly active catalyst for the Heck/Sonogashira coupling reactions

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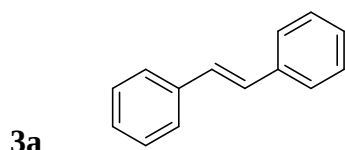
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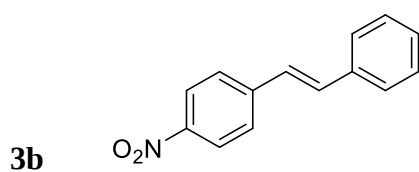
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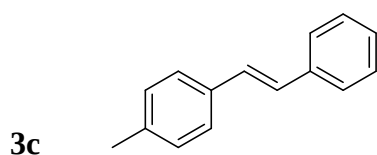
Spectral data



$^1\text{H-NMR}$ (250 MHz, CDCl_3); δ (ppm): 7.53 (d, 4 H, $J = 7.5$ Hz), 7.45 (t, 4 H, $J = 7.5$ Hz), 7.35 (t, 2 H, $J = 7.5$ Hz), 7.26 (s, 2 H), $^{13}\text{C-NMR}$ (60 MHz, CDCl_3); δ (ppm): 139.5, 130.5, 128.5, 126.7, 128.5.

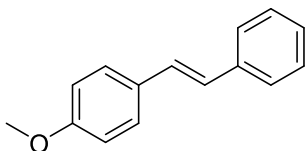


$^1\text{H-NMR}$ (250 MHz, CDCl_3); δ (ppm): 8.40 (d, 2H, $J = 8.5$ Hz), 7.80 (d, 2H, $J = 8.5$ Hz), 7.71 (d, 2H, $J = 7.5$ Hz), 7.45–7.55 (m, 3H), 7.37 (d, 1H, $J = 16.5$ Hz), 7.23 (d, 1H, $J = 16.5$ Hz); $^{13}\text{C-NMR}$ (60 MHz, CDCl_3); δ (ppm): 152.2, 149.9, 140.5, 135.5, 130.1, 129.0, 128.5, 128.0, 127.0, 125.5.



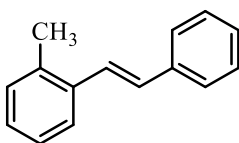
$^1\text{H-NMR}$ (250 MHz, CDCl_3); δ (ppm): 7.42 (d, 2H, $J = 8.5$ Hz), 7.31 (d, 2H, $J = 8.0$ Hz), 7.20 (t, 2H, $J = 7.5$ Hz), 7.15 (t, 1H, $J = 6.5$ Hz), 7.05 (d, 2H, $J = 8.0$ Hz), 6.96 (d, 1H, $J = 16.5$ Hz), 6.90 (d, 1H, $J = 16.5$ Hz), 2.30 (s, 3H); $^{13}\text{C-NMR}$ (60 MHz, CDCl_3); δ (ppm): 136.7, 136.3, 134.2, 130.5, 129.8, 128.7, 127.8, 127.2, 126.0, 126.0, 23.0.

3d



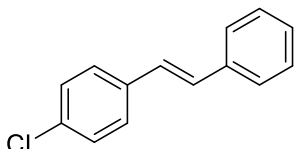
$^1\text{H-NMR}$ (250 MHz, CDCl_3); δ (ppm): 7.42 (d, 2H, $J = 7.5$ Hz), 7.37 (d, 2H, $J = 8.5$ Hz), 7.28 (t, 2H, $J = 7.5$ Hz), 7.18 (t, 1H, $J = 8.5$ Hz), 6.99 (d, 1H, $J = 16.0$ Hz), 6.89 (d, 1H, $J = 16.0$ Hz), 6.80 (d, 2H, $J = 8.5$ Hz), 3.77 (s, 3H); $^{13}\text{C-NMR}$ (60 MHz, CDCl_3); δ (ppm): 160.5, 138.8, 130.9, 129.5, 128.0, 127.5, 127.0, 126.5, 126.0, 116.5, 57.5.

3e



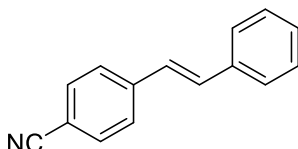
$^1\text{H-NMR}$ (250 MHz, CDCl_3); δ (ppm): 7.41 (d, 2H, $J = 8.0$ Hz), 7.29 (d, 2H, $J = 8.0$ Hz), 7.22 (t, 2H, $J = 8.0$ Hz), 7.12 (t, 1H, $J = 7.5$ Hz), 7.08 (d, 2H, $J = 8.0$ Hz), 6.99 (d, 1H, $J = 7.5$ Hz), 6.88 (d, 1H, $J = 16.5$ Hz), 2.35 (s, 3H); $^{13}\text{C-NMR}$ (60 MHz, CDCl_3); δ (ppm): 136.1, 135.9, 135.2, 130.1, 129.3, 128.4, 128.1, 127.8, 127.7, 126.6, 20.5.

3f



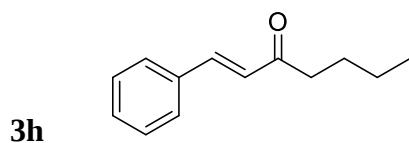
$^1\text{H-NMR}$ (250 MHz, CDCl_3); δ (ppm): 7.80 (d, $J = 7.5$ Hz, 2H), 7.65 (d, $J = 8.5$ Hz, 2H), 7.30-7.44 (m, 5H), 7.20 (s, 2H); $^{13}\text{C-NMR}$ (60MHz, CDCl_3); δ (ppm): 140.0, 137.9, 135.5, 131.3, 129.9, 129.5, 128.2, 127.5, 127.0, 125.5.

3g

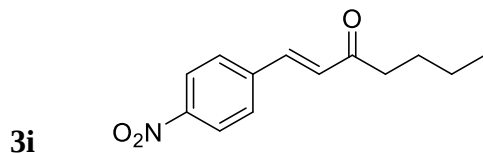


$^1\text{H-NMR}$ (250 MHz, CDCl_3); δ (ppm): 7.45 – 7.60 (m, 6 H), 7.49 (t, 2 H, $J = 7.5$ Hz), 7.40 (t, 1 H, $J = 7.5$ Hz), 7.20 (d, 1 H, $J = 16.5$ Hz), 7.02 (d, 1 H, $J = 16.5$ Hz); $^{13}\text{C-NMR}$ (60MHz,

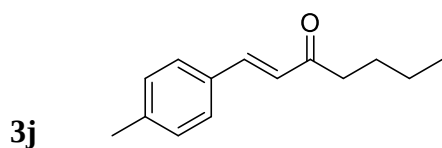
CDCl₃); δ (ppm): 111.9, 119.1, 127.3, 128.1, 128.2, 128.5, 128.6, 129.0, 129.5, 134.2, 135.4, 139.4.



¹H-NMR (250 MHz, CDCl₃); δ (ppm): 7.80 (d, 1H, J = 16.0 Hz), 7.66 (m, 2H), 7.43 (m, 3H), 6.75 (d, 1H, J = 16.0 Hz), 4.45 (t, 2H, J = 6.8 Hz), 2.65 (m, 2H, J = 7.3 Hz), 1.80 (m, 2H, J = 7.3 Hz), 1.05 (t, 3H, J = 7.3 Hz); ¹³C-NMR (60 MHz, CDCl₃); δ (ppm): 170.5, 151.5, 140.8, 135.6, 130.2, 129.5, 120.8, 71.6, 35.0, 22.2, 15.5.

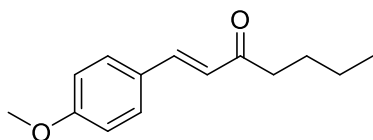


¹H-NMR (250 MHz, CDCl₃); δ (ppm): 8.65 (d, 2H, J = 8.0 Hz), 7.98–7.88 (m, 3H), 7.09 (d, 1H, J = 15.5 Hz), 5.65 (t, 2H, J = 7.5 Hz), 2.45 (m, 2H, J = 8.0 Hz), 1.86 (m, 2H, J = 7.5 Hz), 1.08 (t, 3H, J = 7.5 Hz); ¹³C-NMR (60 MHz, CDCl₃); δ (ppm): 184.0, 166.5, 155.5, 138.7, 133.5, 129.5, 123.3, 87.7, 54.4, 28.8, 15.5.



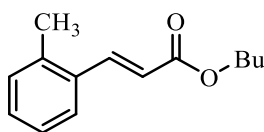
¹H-NMR (250 MHz, CDCl₃); δ (ppm): 7.87 (d, 1H, J = 16.0 Hz), 7.55 (d, 2H, J = 8.5 Hz), 7.25 (d, 2H, J = 8.5 Hz), 6.60 (d, 1H, J = 16.0 Hz), 4.90 (t, 2H, J = 8.5 Hz), 2.80 (s, 3H), 1.99 (m, 2H, J = 7.5 Hz), 1.20 (m, 2H, J = 7.5 Hz), 0.88 (t, 3H, J = 7.5 Hz); ¹³C-NMR (60 MHz, CDCl₃); δ (ppm): 175.5, 150.6, 144.5, 130.0, 129.0, 128.5, 119.0, 70.5, 41.3, 25.7, 17.5, 13.0.

3k



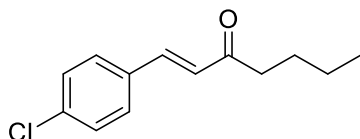
$^1\text{H-NMR}$ (250 MHz, CDCl_3); δ (ppm): 1.07 (t, $J = 7.5$ Hz, 3H), 1.30-1.42 (m, 2H), 1.59-1.70 (m, 2H), 3.67 (s, 3H), 4.05 (t, $J = 7.0$ Hz, 2H), 6.46 (d, $J = 16.0$, 1H), 6.70-6.90 (m, 2H), 7.35-7.50 (m, 2H), 7.65 (d, $J = 16.0$, 1H); $^{13}\text{C-NMR}$ (60 MHz, CDCl_3); δ (ppm): 162.43, 150.21, 159.09, 126.72, 125.08, 118.05, 110.05, 60.19, 44.34, 35.67, 21.20, 12.05.

3l

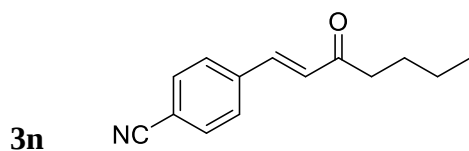


$^1\text{H-NMR}$ (250 MHz, CDCl_3); δ (ppm): 7.87 (d, 1H, $J = 6.5$ Hz), 7.56 (d, 2H, $J = 8.5$ Hz), 7.24 (d, 2H, $J = 8.5$ Hz), 6.59 (d, 1H, $J = 6.5$ Hz), 4.88 (t, 2H, $J = 6.5$ Hz), 2.34 (s, 3H), 1.95 (m, 2H, $J = 6.0$ Hz), 1.18 (m, 2H, $J = 7.6$ Hz), 0.88 (t, 3H, $J = 7.5$ Hz); $^{13}\text{C-NMR}$ (60 MHz, CDCl_3); δ (ppm): 175.2, 150.4, 144.5, 129.5, 128.9, 128.7, 118.8, 70.4, 41.0, 20.1, 17.7, 13.2.

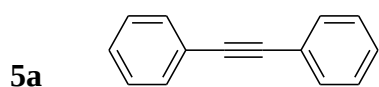
3m



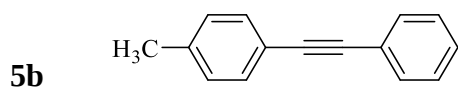
$^1\text{H-NMR}$ (250 MHz, CDCl_3); δ (ppm): 1.09 (t, $J = 7.5$ Hz, 3H), 1.44-1.51 (m, 2H), 1.70-1.85 (m, 2H), 3.99 (t, $J = 7.5$ Hz, 2H), 5.87 (d, $J = 16.0$, 1H), 7.43- 7.50 (m, 2H), 7.54-7.78 (m, 2H), 7.89 (d, $J = 16.0$, 1H); $^{13}\text{C-NMR}$ (60 MHz, CDCl_3); δ (ppm): 175.8, 152.1, 134.4, 130.1, 127.7, 125.5, 108.8, 74.6, 47.5, 25.1, 15.5.



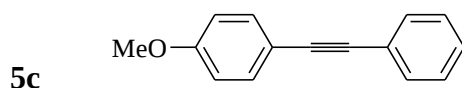
^1H -NMR (250 MHz, CDCl_3); δ (ppm): 7.82–7.69 (m, 5H), 6.90 (d, 1H, $J = 16.0$ Hz), 5.45 (t, 2H, $J = 7.0$ Hz), 2.23 (m, 2H, $J = 7.5$ Hz), 1.99 (m, 2H, $J = 7.5$ Hz), 1.07 (t, 3H, $J = 7.5$ Hz); ^{13}C -NMR (60 MHz, CDCl_3); δ (ppm): 184.5, 163.3, 151.2, 145.5, 133.7, 128.2, 121.9, 119.0, 86.5, 42.8, 25.5, 16.7.



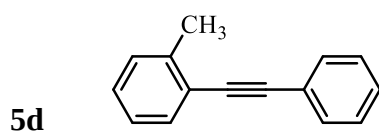
^1H NMR (250 MHz, CDCl_3) δ (ppm): 7.43-7.47 (m, 3H), 7.28-7.23 (m, 6 H); ^{13}C NMR (62.9 MHz, CDCl_3) δ (ppm): 132.5, 128.3, 128.2, 123.2, 89.3.



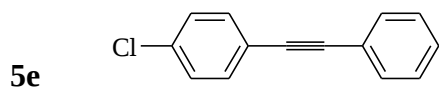
^1H NMR (250 MHz, CDCl_3) δ (ppm): 7.42-7.44 (m, 2H), 7.30-7.36 (m, 2H), 7.20-7.25 (m, 3H), 6.99-7.08 (m, 2H), 2.27 (s, 3H); ^{13}C NMR (62.9 MHz, CDCl_3) δ (ppm): 138.4, 131.6, 131.5, 129.1, 128.2, 128.1, 123.5, 120.2, 89.6, 88.7, 21.5.



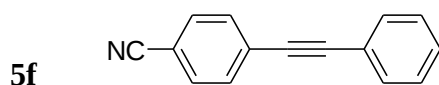
^1H NMR (250 MHz, CDCl_3) δ (ppm): 7.37-7.43 (m, 4H), 7.22-7.25 (m, 3 H), 6.79 (d, 2 H, $J=8.2$), 3.73 (s, 3H); ^{13}C NMR (62.9 MHz, CDCl_3) δ (ppm): 159.6, 133.0, 131.4, 128.3, 127.9, 123.5, 115.3, 113.9, 89.3, 88.0, 55.2.



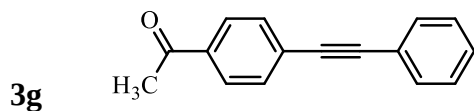
^1H NMR (250 MHz, CDCl_3) δ (ppm): 7.44-7.49 (m, 2H), 7.29-7.33 (m, 2H), 7.21-7.24 (m, 3H), 7.11-7.16 (m, 2H), 2.34 (s, 3H); ^{13}C NMR (62.9 MHz, CDCl_3) δ (ppm): 138.4, 131.6, 131.5, 129.1, 128.2, 128.1, 123.5, 120.2, 89.6, 88.7, 21.5.



^1H NMR (250 MHz, CDCl_3) δ (ppm): 7.13-7.25 (m, 3H), 7.33-7.43 (m, 6H); ^{13}C NMR (62.9 MHz, CDCl_3) δ (ppm): 134.2, 132.8, 131.6, 128.7, 128.5, 128.4, 122.9, 121.8, 90.3, 88.2.



^1H NMR (250 MHz, CDCl_3) δ (ppm): 7.71-7.75 (m, 3H), 7.26-7.41 (m, 4H), 7.61-7.71 (m, 2H); ^{13}C NMR (62.9 MHz, CDCl_3) δ (ppm): 134.6, 132.7, 131.4, 128.6, 128.2, 128.7, 123.3, 121.5, 91.7, 88.5.



^1H NMR (250 MHz, CDCl_3) δ (ppm): 7.61-7.69 (m, 4H), 7.24-7.32 (m, 3 H), 6.91 (d, 2 H, $J=8.2$), 2.54 (s, 3H); ^{13}C NMR (62.9 MHz, CDCl_3) δ (ppm): 197.1, 160.3, 132.8, 131.6, 128.5, 128.2, 123.3, 115.0, 114.2, 89.3, 85.8, 78.6, 27.8.