Byproduct Promoted Regioselective Sulfenylation of Indoles with Sulfinic Acids

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Supporting Information

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General Information

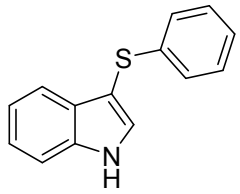
^{1}H and ^{13}C NMR spectra were recorded on a Bruker AC-400 FT (400 MHz and 100 MHz, respectively) using tetramethylsilane as an internal reference. NMR multiplicities are abbreviated as follows: s = singlet, d = doublet, m = multiplet, br = broad signal. Chemical shifts (δ) and coupling constants (J) were expressed in ppm and Hz, respectively.

2a-2m were prepared according to the literature procedure.[1] The rest of chemicals were purchased from the Sinopharm Chemical Reagent Co., Meryer, Acros, Alfa Aesar, and TCI, and used as received.

General Procedure for Byproduct Promoted Regioselective Sulfenylation of Indoles with Sulfinic Acids (Tables 2 and table 3)

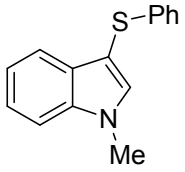
To a solution of indole **1** (0.20 mmol) in DCE (1.0 mL) were added sulfinic acid (0.24 mmol), tetrabutylammonium iodide (88.6 mg, 0.24 mmol) and TsOH (6.9 mg, 0.040 mmol). The resulting mixture was stirred at 80 ^{o}C for 12 h. The mixture was cooled to room temperature, and purified by flash column chromatography on silica gel, eluting with petroleum ether/ethyl acetate (100:1 to 10:1), to give compound **3**.

Analytical Data for the Products Shown in Tables 2 and 3



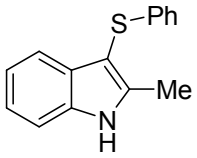
3a

3a, [2] white solid, m.p. 151–154 ^{o}C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.35 (s, 1H), 7.61 (d, J = 8.0 Hz, 1H), 7.47–7.39 (m, 2H), 7.29–7.22 (m, 1H), 7.19–7.00 (m, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 139.2, 136.5, 130.7, 129.1, 128.7, 125.9, 124.8, 123.1, 120.9, 119.7, 111.6, 102.9.



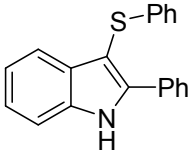
3b

3b, [2] white solid, m.p. 81–83 ^{o}C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.60 (d, J = 8.0 Hz, 1H), 7.34 (d, J = 8.0 Hz, 1H), 7.30–7.23 (m, 2H), 7.19–7.05 (m, 5H), 7.05–6.97 (m, 1H), 3.76 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 139.7, 137.5, 135.0, 129.8, 128.6, 125.7, 124.6, 122.5, 120.5, 119.7, 109.7, 100.5, 33.0.



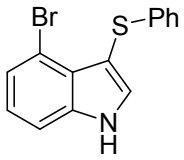
3c

3c, [2] white solid, m.p. 111–112 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.14 (s, 1H), 7.54 (d, J = 7.6 Hz, 1H), 7.30 (d, J = 8.0 Hz, 1H), 7.21–7.07 (m, 4H), 7.06–6.97 (m, 3H), 2.46 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 141.1, 139.3, 135.4, 130.3, 128.7, 125.5, 124.5, 122.2, 120.7, 119.0, 110.6, 99.3, 12.1.



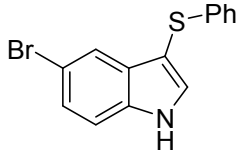
3d

3d, [2] colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.52 (s, 1H), 7.75–7.70 (m, 2H), 7.62 (d, J = 7.6 Hz, 1H), 7.43–6.98 (m, 11H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 142.1, 139.3, 135.9, 131.5, 131.2, 128.9, 128.8, 128.7, 128.2, 125.6, 124.7, 123.4, 121.2, 120.0, 111.2.



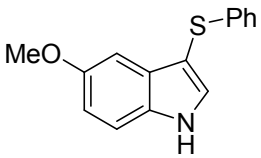
3e

3e, [2] white solid, m.p. 135–137 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.51 (s, 1H), 7.49 (d, J = 2.8 Hz, 1H), 7.40–7.30 (m, 2H), 7.21–7.14 (m, 2H), 7.12–7.02 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 141.0, 137.7, 133.1, 128.7, 126.3, 125.9, 124.7, 124.0, 114.7, 111.1, 103.8.



3f

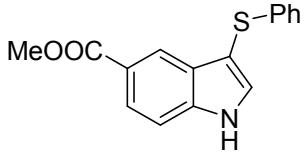
3f, [2] white solid, m.p. 118–120 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.66 (s, 1H), 7.74 (d, J = 1.6 Hz, 1H), 7.43 (d, J = 2.4 Hz, 1H), 7.35–7.23 (m, 2H), 7.19–7.12 (m, 2H), 7.10–7.02 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 138.8, 135.2, 132.0, 131.0, 128.8, 126.0, 125.9, 125.0, 122.1, 114.4, 113.1, 102.5.



3g

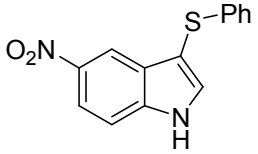
3g, [2] white solid, m.p. 77–80 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.36 (s, 1H), 7.35 (d, J = 2.8 Hz, 1H), 7.24 (d, J = 8.8 Hz, 1H), 7.18–7.00 (m, 6H), 6.92–6.85 (m, 1H), 3.74 (s, 3H); ^{13}C NMR

(100 MHz, $CDCl_3$) δ 155.1, 139.3, 131.4, 129.9, 128.7, 125.6, 124.7, 113.5, 112.5, 101.9, 100.8, 55.8.



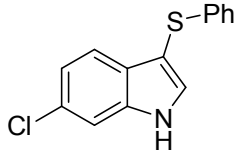
3h

3h, [2] white solid, m.p. 172–175 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.70 (s, 1H), 8.40–8.36 (m, 1H), 8.02–7.94 (m, 1H), 7.56 (d, J = 2.8 Hz, 1H), 7.46 (d, J = 8.8 Hz, 1H), 7.20–7.12 (m, 2H), 7.12–7.02 (m, 3H), 3.89 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.9, 139.1, 138.8, 132.1, 128.9, 128.8, 126.0, 125.0, 124.5, 123.2, 122.5, 111.4, 104.8, 51.9.



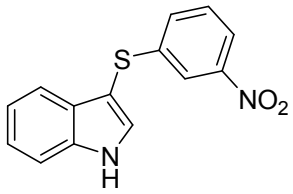
3i

3i, [2] yellow solid, m.p. 151–154 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.93 (s, 1H), 8.57 (d, J = 2.4Hz, 1H), 8.20–8.14 (m, 1H), 7.66 (d, J = 2.4 Hz, 1H), 7.53–7.46 (m, 1H), 7.23–7.15 (m, 2H), 7.15–7.05 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 142.9, 139.5, 137.8, 133.6, 129.0, 128.9, 126.5, 125.6, 118.7, 116.9, 111.9, 106.7.



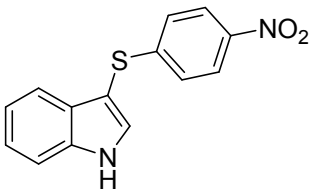
3j

3j, [2] white solid, m.p. 106–108°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.39 (s, 1H), 7.52–7.44 (m, 2H), 7.42 (d, J = 1.6 Hz, 1H), 7.20–7.02 (m, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 138.7, 136.8, 131.1, 129.1, 128.8, 127.7, 126.0, 125.0, 121.7, 120.6, 111.6, 103.5.



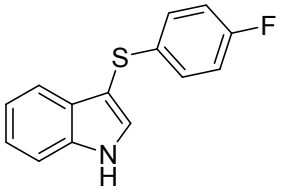
3k

3k, [2] white solid, m.p. 130–133 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.58 (s, 1H), 7.94–7.84 (m, 2H), 7.58–7.52 (m, 2H), 7.50–7.45 (m, 1H), 7.39–7.33 (m, 1H), 7.32–7.25 (m, 2H), 7.22–7.15 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 148.7, 142.6, 136.6, 131.3, 129.3, 128.5, 123.5, 121.3, 120.3, 119.7, 119.2, 111.9, 100.9.



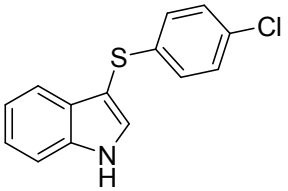
3l

3l, [2] yellow solid, m.p. 180–183 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.71 (s, 1H), 8.01–7.93 (m, 2H), 7.54–7.46 (m, 3H), 7.34–7.27 (m, 1H), 7.22–7.15 (m, 1H), 7.15–7.08 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 149.9, 144.9, 136.6, 131.3, 128.4, 125.1, 123.9, 123.5, 121.4, 119.2, 112.0, 100.1.



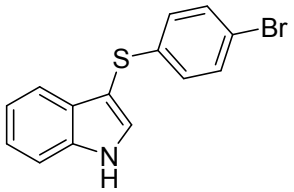
3m

3m, [2] white solid, m.p. 130–133 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.36 (s, 1H), 7.59 (d, J = 8.8 Hz, 1H), 7.47–7.39 (m, 2H), 7.29–7.22 (m, 1H), 7.20–7.12 (m, 1H), 7.11–7.04 (m, 2H), 6.90–6.82 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.9 (d, J = 243 Hz), 136.5, 134.0 (d, J = 2.9 Hz), 130.5, 128.9, 127.9 (d, J = 7.8 Hz), 123.2, 121.0, 119.6, 115.8 (d, J = 22 Hz), 111.7, 103.4.



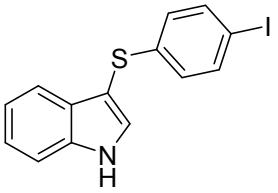
3n

3n, [2] white solid, m.p. 130–132 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.39 (s, 1H), 7.57 (d, J = 8.0 Hz, 1H), 7.47–7.39 (m, 2H), 7.30–7.22 (m, 1H), 7.20–7.13 (m, 1H), 7.12–7.07 (m, 2H), 7.04–6.97 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 137.9, 136.5, 130.7, 130.6, 128.8, 127.2, 123.2, 121.1, 119.5, 111.7, 102.5.



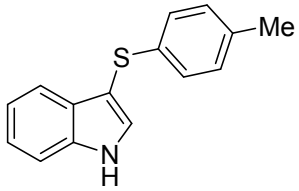
3o

3o, [2] white solid, m.p. 144–147 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.40 (s, 1H), 7.59–7.53 (m, 1H), 7.46–7.39 (m, 2H), 7.30–7.21 (m, 3H), 7.20–7.13 (m, 1H), 6.97–6.90 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 138.6, 136.5, 131.7, 130.8, 128.8, 127.5, 123.3, 121.1, 119.5, 118.4, 111.7, 102.3.



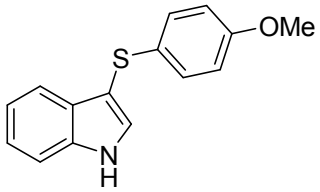
3p

3p, [2] white solid, m.p. 129–132 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.43 (s, 1H), 7.58–7.53 (m, 1H), 7.48–7.40 (m, 4H), 7.31–7.22 (m, 1H), 7.20–7.13 (m, 1H), 6.85–6.79 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 139.6, 137.5, 136.5, 130.8, 128.8, 127.7, 123.3, 121.1, 119.5, 111.7, 102.1, 89.0.



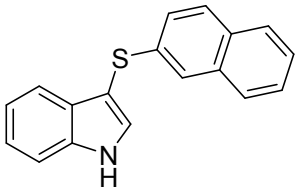
3q

3q, [2] white solid, m.p. 125–127 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.19 (s, 1H), 7.60 (d, J = 7.6 Hz, 1H), 7.35–7.31 (m, 2H), 7.25–7.18 (m, 1H), 7.16–7.10 (m, 1H), 7.02 (d, J = 8.4 Hz, 2H), 6.94 (d, J = 8.4 Hz, 2H), 2.22 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 136.4, 135.4, 134.7, 130.5, 129.5, 129.0, 126.3, 122.9, 120.8, 119.6, 111.6, 103.3, 20.8.



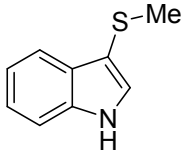
3r

3r, [2] yellow solid, m.p. 111–112 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.29 (s, br, 1H), 7.62 (d, J = 8.0 Hz, 1H), 7.39–7.32 (m, 2H), 7.26–7.18 (m, 1H), 7.17–7.08 (m, 3H), 6.75–6.68 (m, 2H), 3.70 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 157.8, 136.5, 130.1, 129.6, 129.0, 128.6, 123.0, 120.8, 119.6, 114.6, 111.6, 104.5, 55.4.



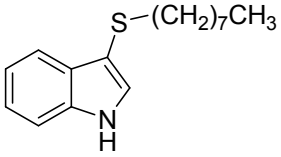
3s

3s, [2] white solid, m.p. 140–142 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.45 (s, 1H), 7.74–7.69 (m, 1H), 7.66–7.59 (m, 2H), 7.59–7.52 (m, 2H), 7.50–7.48 (m, 1H), 7.47–7.43 (m, 1H), 7.40–7.31 (m, 2H), 7.30–7.24 (m, 2H), 7.18–7.11 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 136.7, 136.6, 133.8, 131.3, 130.7, 129.1, 128.2, 127.7, 126.9, 126.3, 125.0, 124.8, 123.6, 123.1, 121.0, 119.7, 111.6, 102.9.



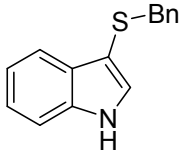
3t

3t, [2] colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.16 (s, 1H), 7.79–7.74 (m, 1H), 7.39–7.34 (m, 1H), 7.29 (d, J = 2.8 Hz, 1H), 7.27–7.17 (m, 2H), 2.37 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 136.3, 128.8, 127.8, 122.7, 120.4, 119.3, 111.5, 108.3, 20.2.



3u

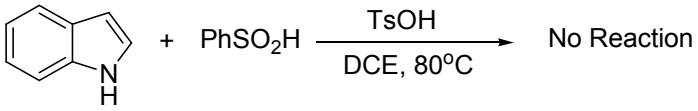
3u, [2] yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.19 (s, 1H), 7.80–7.75 (m, 1H), 7.40–7.35 (m, 1H), 7.31 (d, J = 2.4 Hz, 1H), 7.27–7.15 (m, 2H), 2.69 (t, J = 7.6 Hz, 2H), 1.59–1.49 (m, 2H), 1.39–1.31 (m, 2H), 1.30–1.21 (m, 8H), 0.86 (t, J = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 136.3, 129.5, 129.2, 122.6, 120.4, 119.5, 111.4, 106.4, 36.5, 31.8, 29.9, 29.2, 28.6, 22.6, 14.1.



3v

3v, [2] yellow solid, m.p. 80–82 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.10 (s, 1H), 7.72–7.67 (m, 1H), 7.34 (d, J = 7.6 Hz, 1H), 7.26–7.14 (m, 5H), 7.10–7.04 (m, 2H), 6.98 (d, J = 2.4 Hz, 1H), 3.86 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 139.1, 136.2, 129.9, 129.3, 129.0, 128.2, 126.8, 122.7, 120.5, 119.3, 111.5, 105.3, 41.0.

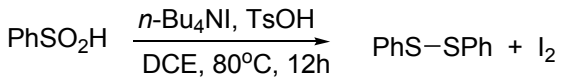
Sulfenylation of Indoles with Sulfinic Acids in the Abscence of Tetrabutylammonium Iodide



1a **2a**

To a solution of indole **1a** (23.4 mg, 0.20 mmol) in DCE (1.0 mL) were added benzenesulfinic acid **2a** (34.1 mg, 0.24 mmol) and TsOH (6.9 mg, 0.040 mmol). The resulting mixture was stirred at 80 °C for 12 h. The mixture was cooled to room temperature, and detect by TLC, found no compound **3a**.

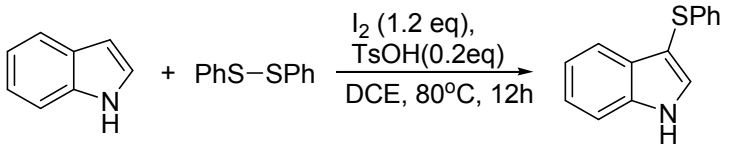
Reduction of Benzenesulfinic Acid 2a



2a **4a** : (96%)

To a solution of benzenesufinic acid **2a** (34.1 mg, 0.24 mmol) in DCE (1.0 mL) were added tetrabutylammonium iodide (88.6 mg, 0.24 mmol) and TsOH (6.9 mg, 0.040 mmol). The resulting mixture was stirred at 80 °C for 12 h. The mixture was cooled to room temperature, and purified by flash column chromatography on silica gel, eluting with petroleum ether, to give compound **4a** (50.2 mg, 96%).

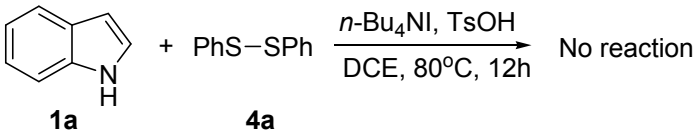
Reaction of Indole 1a with Diphenyldisulfane 4a in 1.2 eq I_2



1a **4a** **3a** : 99%

To a solution of indole **1a** (23.4 mg, 0.20 mmol) in DCE (1.0 mL) were added diphenyldisulfane **4a** (52.3 mg, 0.24 mmol), iodine (61.0 mg, 0.24 mmol) and TsOH (6.9 mg, 0.040 mmol). The resulting mixture was stirred at 80 °C for 12 h. The mixture was cooled to room temperature, and purified by flash column chromatography on silica gel, eluting with petroleum ether/ethyl acetate (30:1), to give compound **3a** (44.6 mg, 99%).

Reaction of Indole 1a with Diphenyldisulfane 4a under the Optimized Reaction Conditions



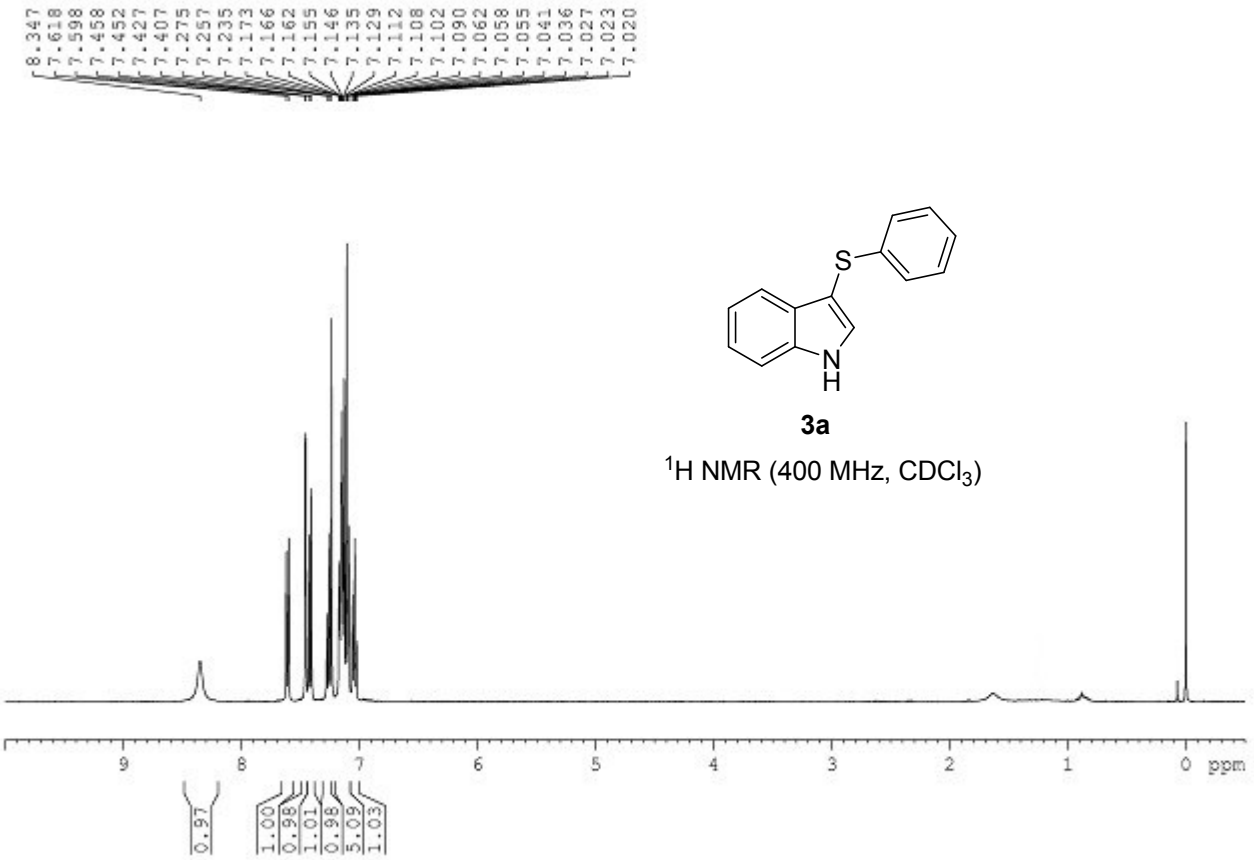
1a **4a**

To a solution of indole **1a** (23.4 mg, 0.20 mmol) in DCE (1.0 mL) were added diphenyldisulfane **4a** (52.3 mg, 0.24 mmol), tetrabutylammonium iodide (88.6 mg, 0.24 mmol) and TsOH (6.9 mg, 0.040 mmol). The resulting mixture was stirred at 80 °C for 12 h. The mixture was cooled to room temperature, and detect by TLC, found no compound **3a**.

References

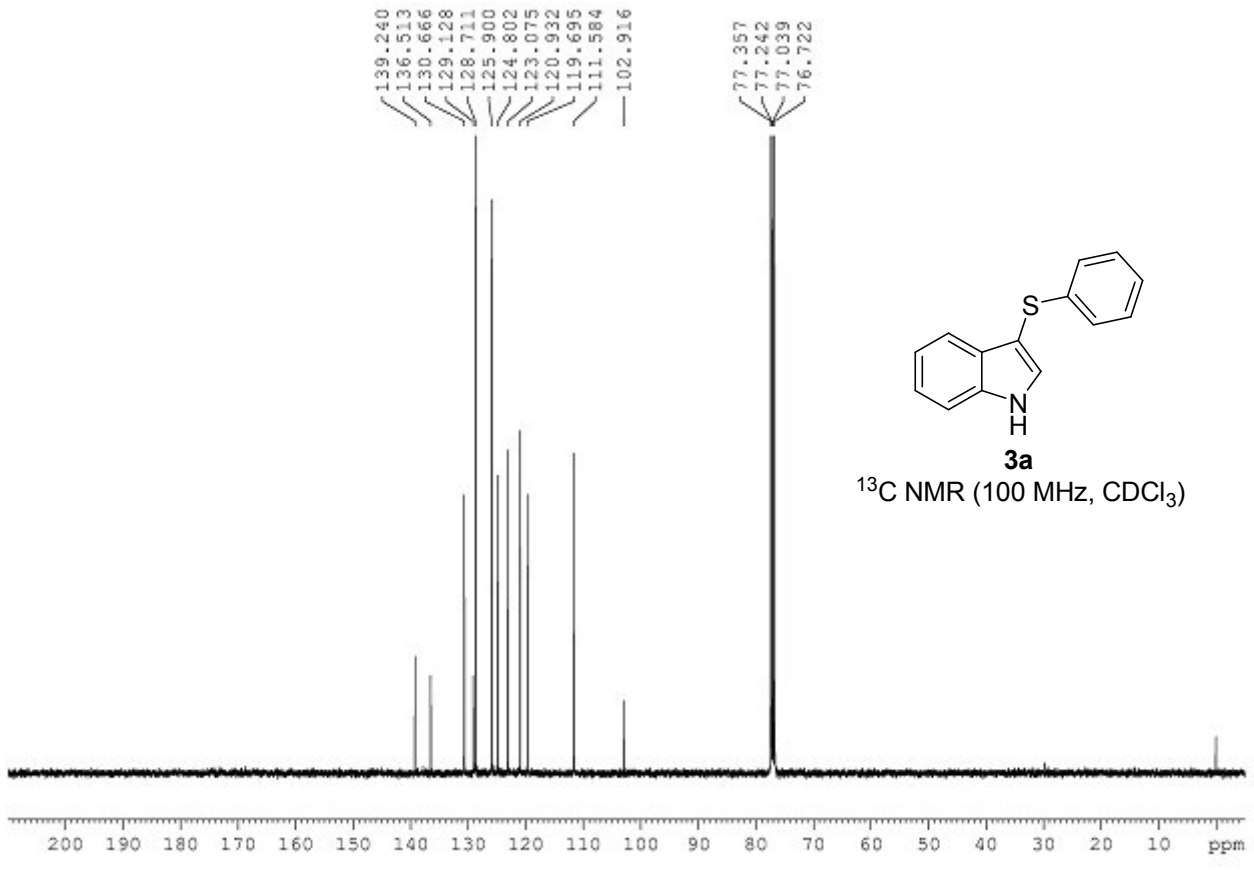
[1] M. Conrads, J. Matty, *Synthesis*. 1991, **11**, 2367.

[2] F.- L.Yang, S.-K.Tian, *Angew. Chem.* 2013, **125**, 5029; *Angew. Chem. Int. Ed*. 2013, **52**, 4929.



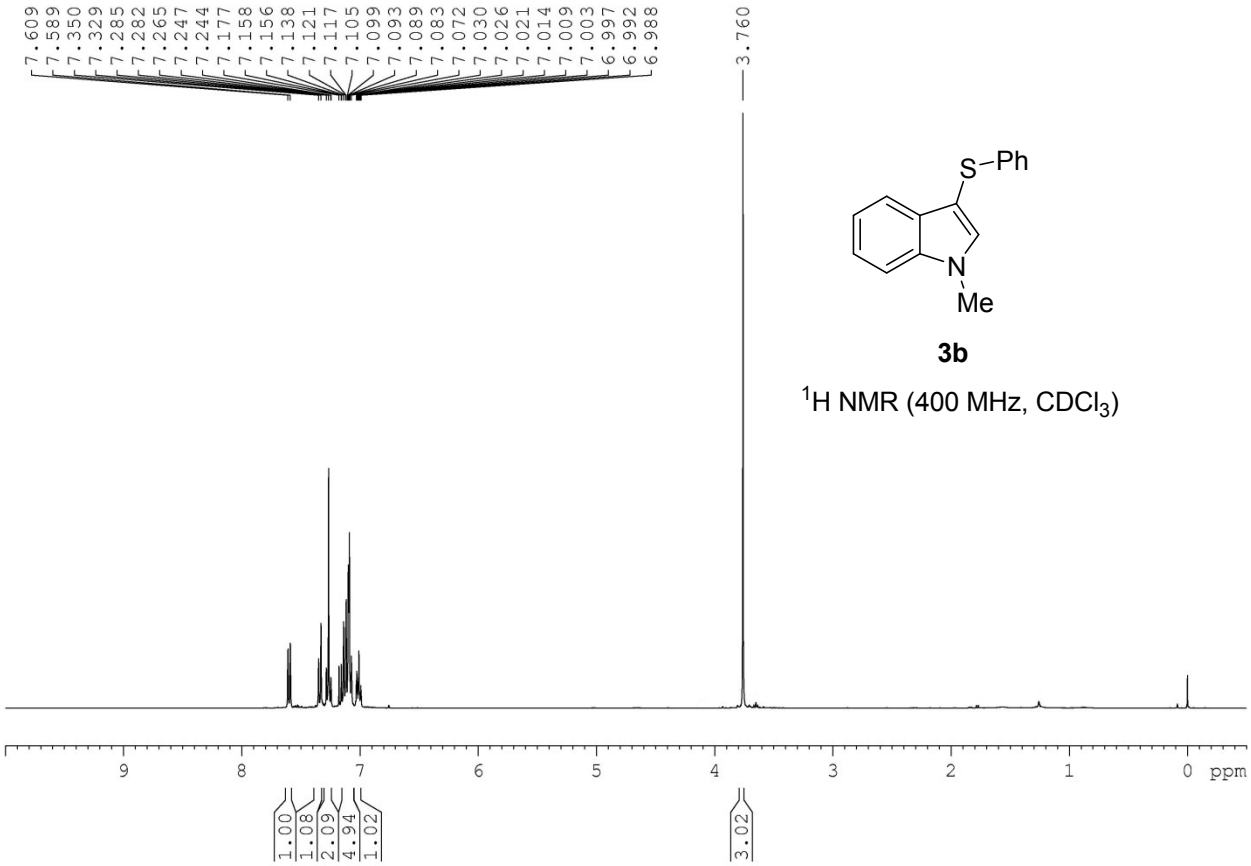
3a

^{1}H NMR (400 MHz, $CDCl_3$)



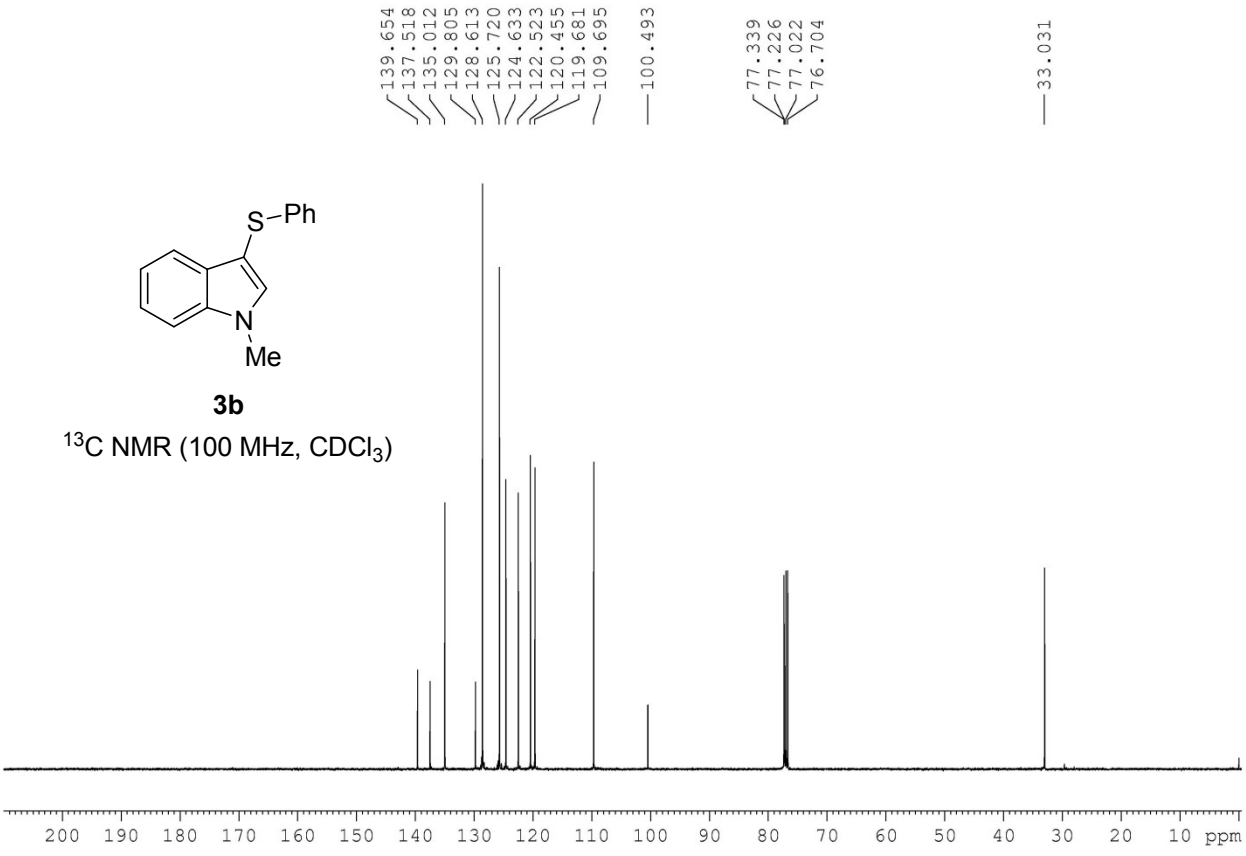
3a

^{13}C NMR (100 MHz, $CDCl_3$)



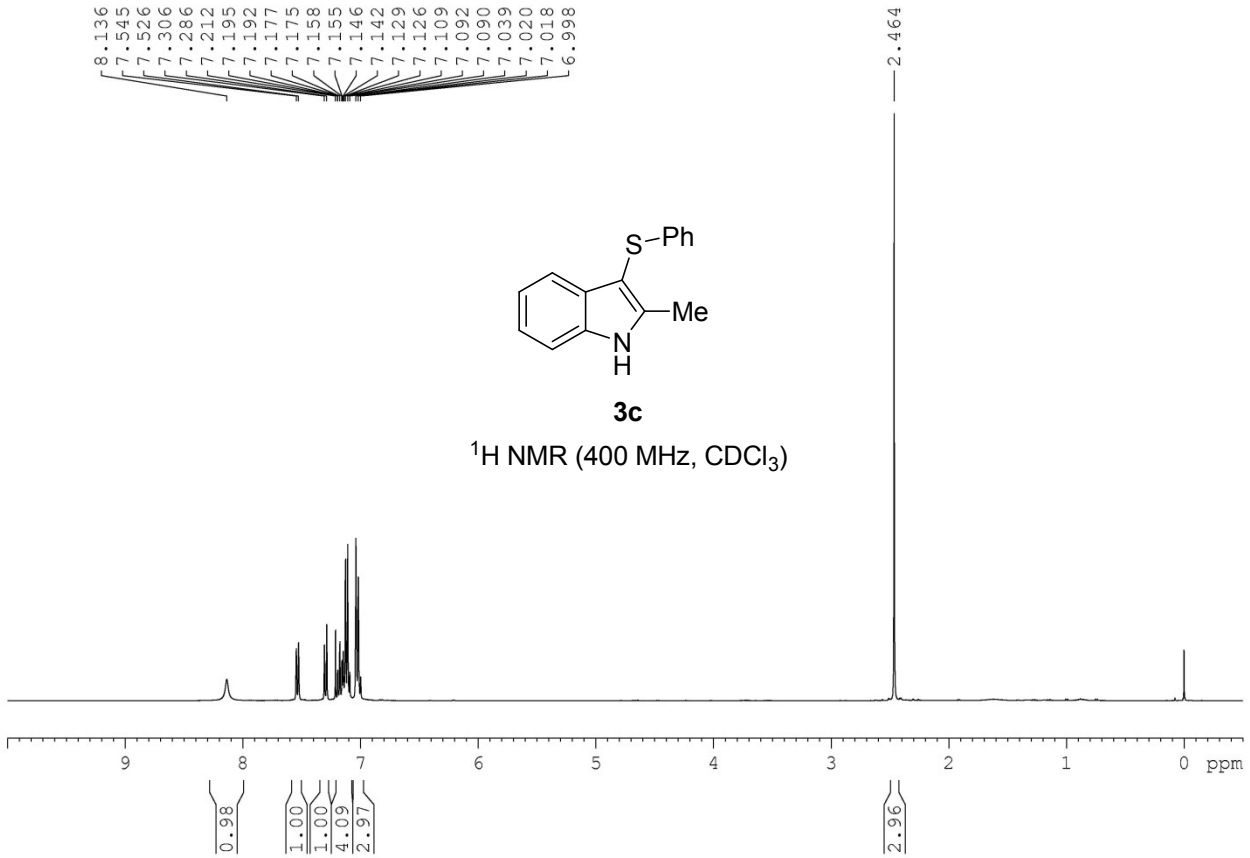
3b

^{1}H NMR (400 MHz, $CDCl_3$)



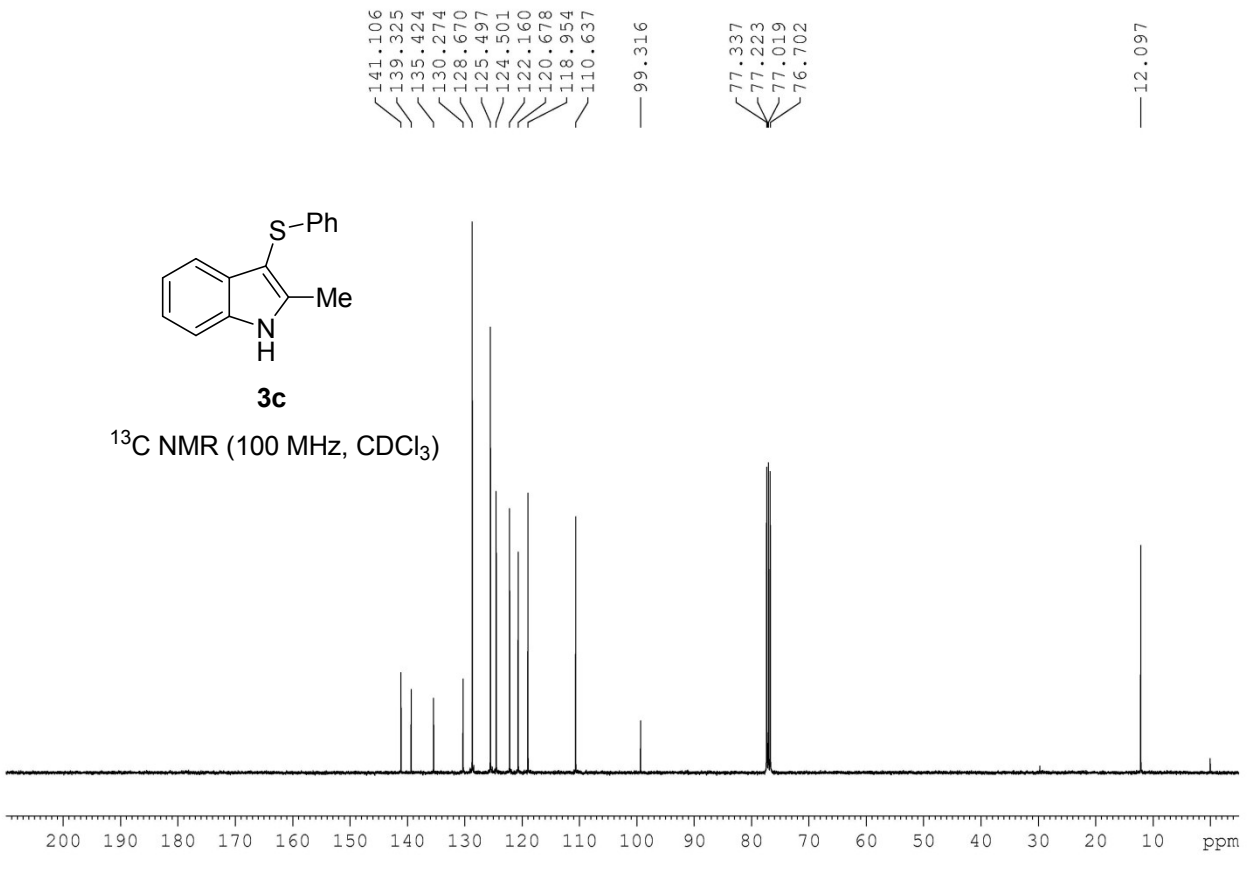
3b

^{13}C NMR (100 MHz, $CDCl_3$)



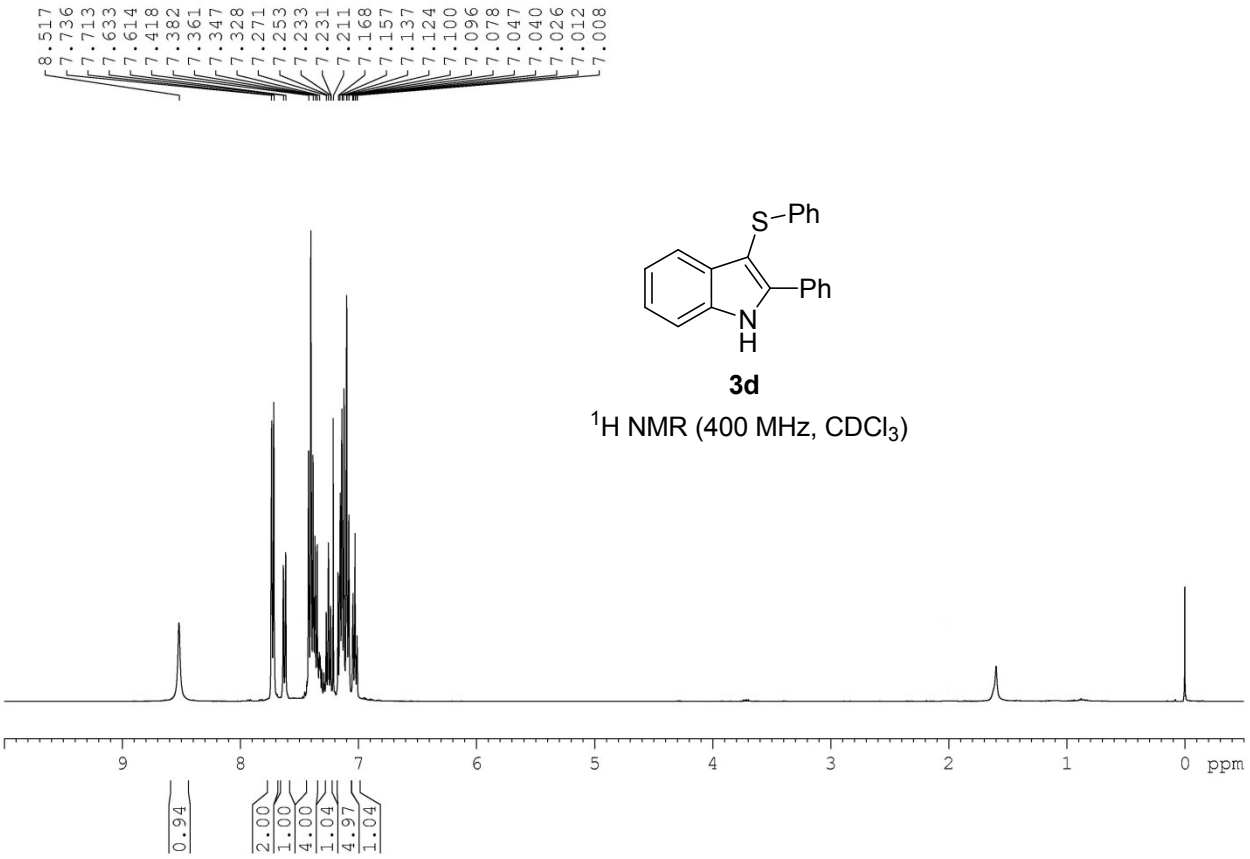
3c

^{1}H NMR (400 MHz, $CDCl_3$)



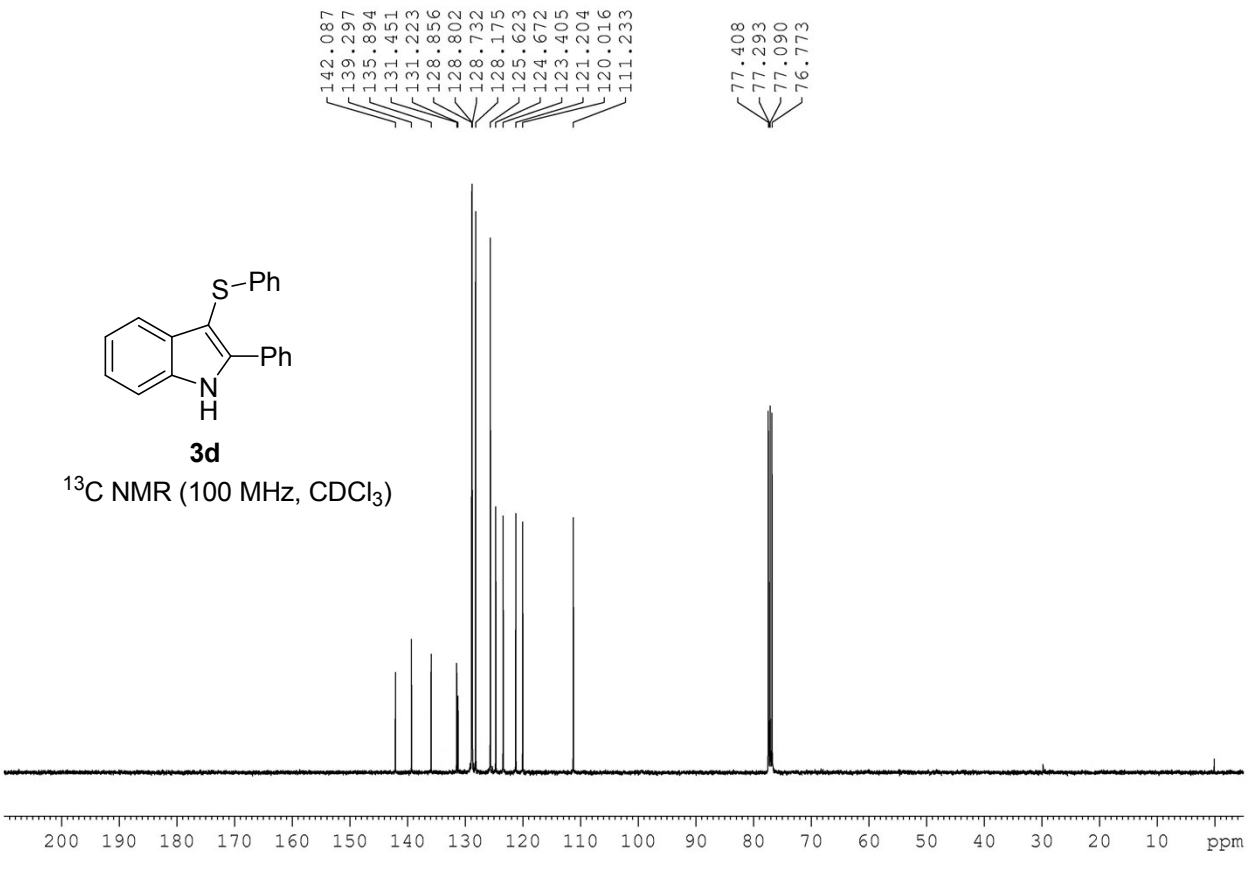
3c

^{13}C NMR (100 MHz, $CDCl_3$)



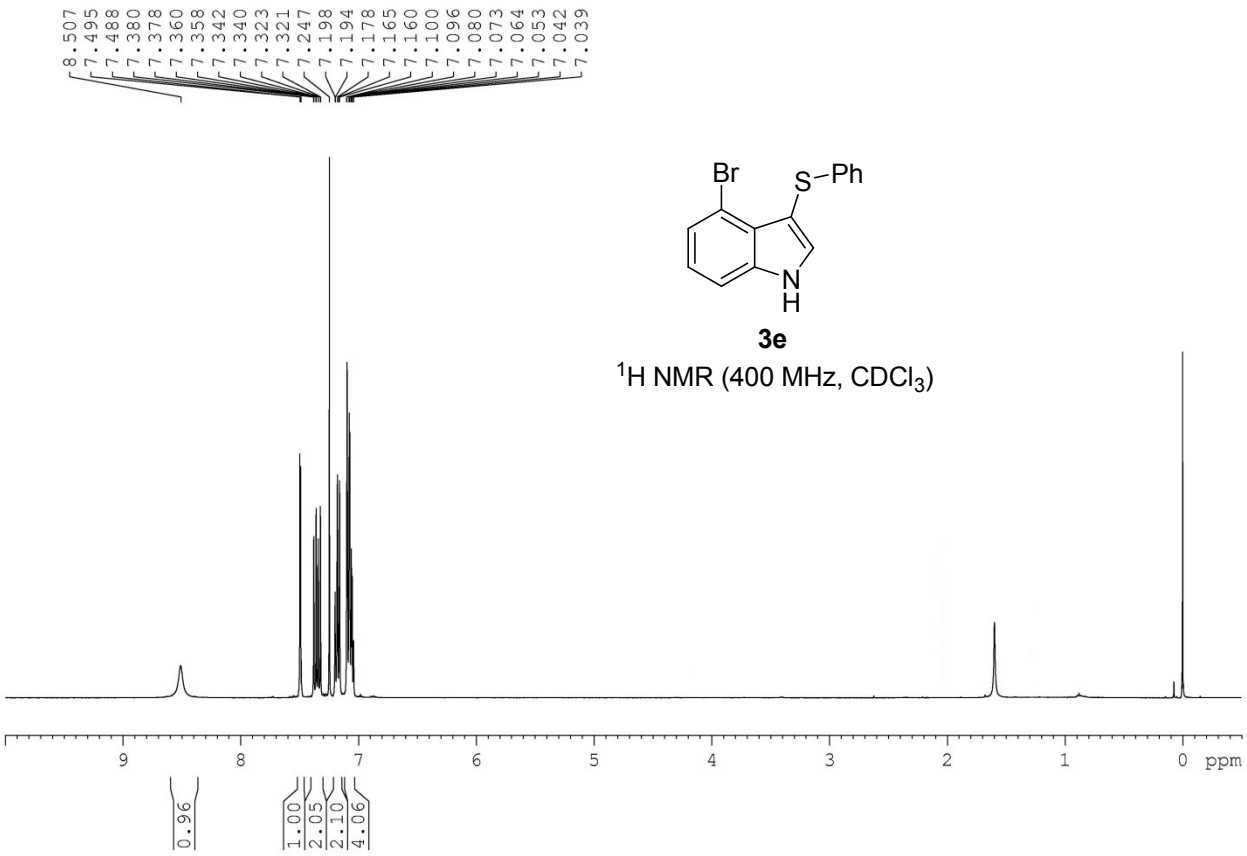
3d

^{1}H NMR (400 MHz, $CDCl_3$)



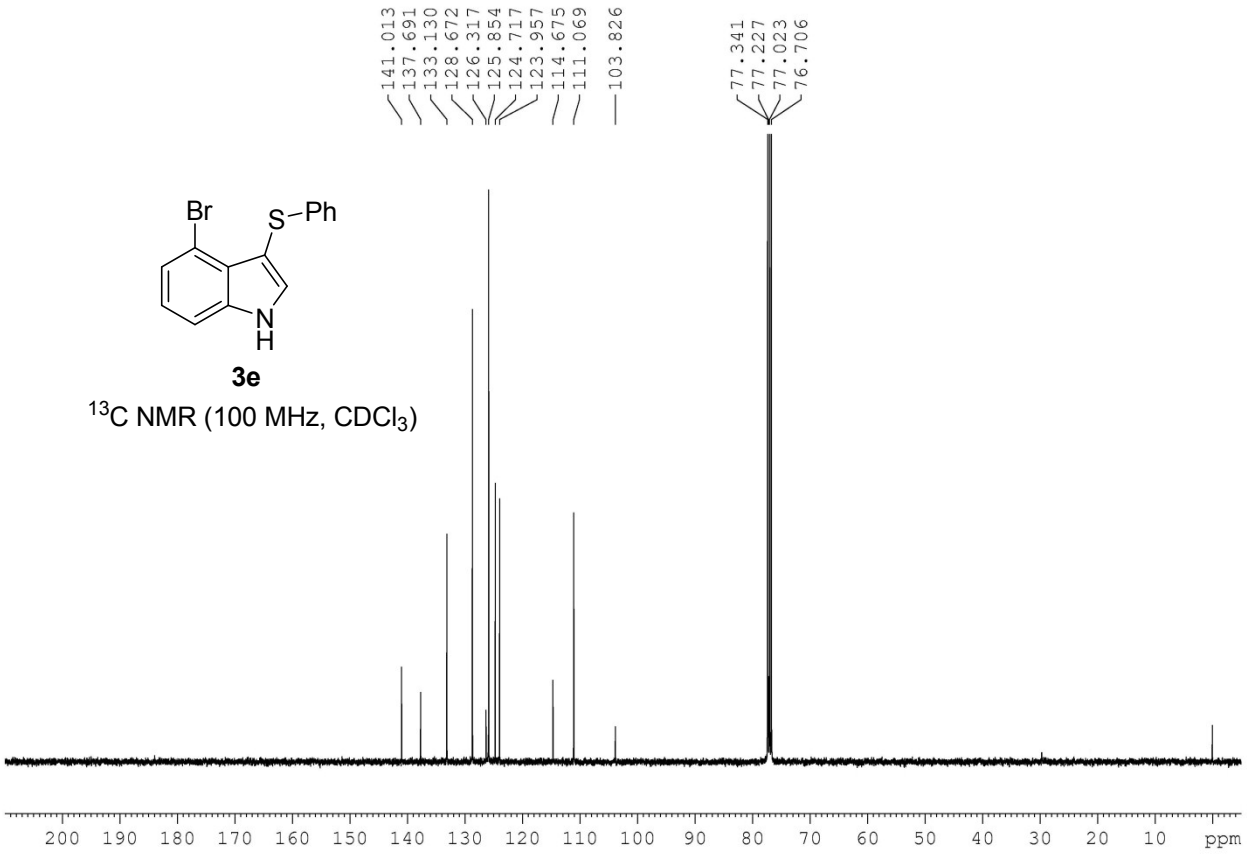
3d

^{13}C NMR (100 MHz, $CDCl_3$)



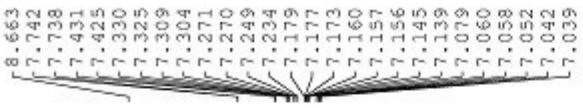
3e

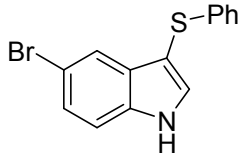
^{1}H NMR (400 MHz, $CDCl_3$)



3e

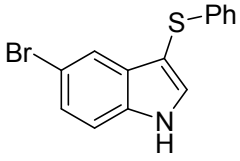
^{13}C NMR (100 MHz, $CDCl_3$)





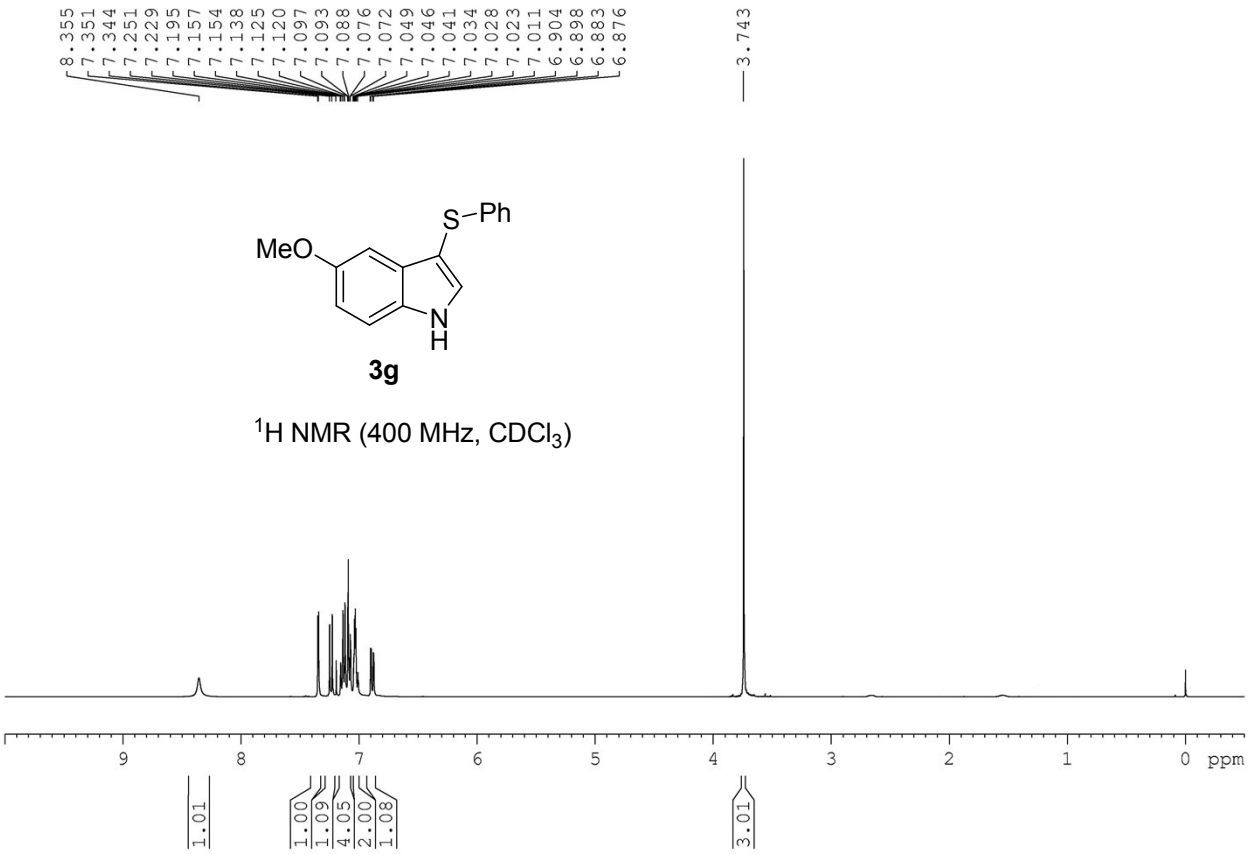
3f

^{1}H NMR (400 MHz, $CDCl_3$)



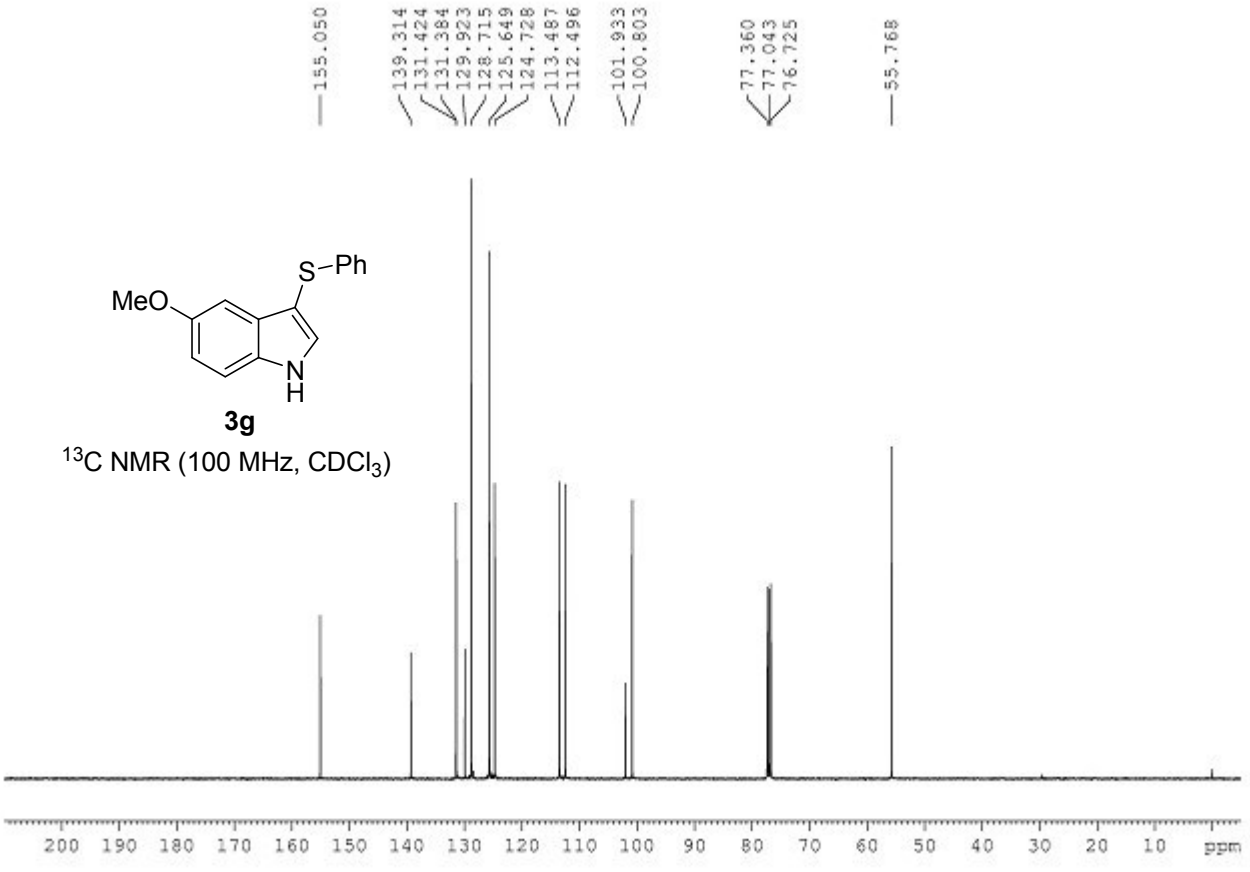
3f

^{13}C NMR (100 MHz, $CDCl_3$)



3g

^{1}H NMR (400 MHz, $CDCl_3$)



3g

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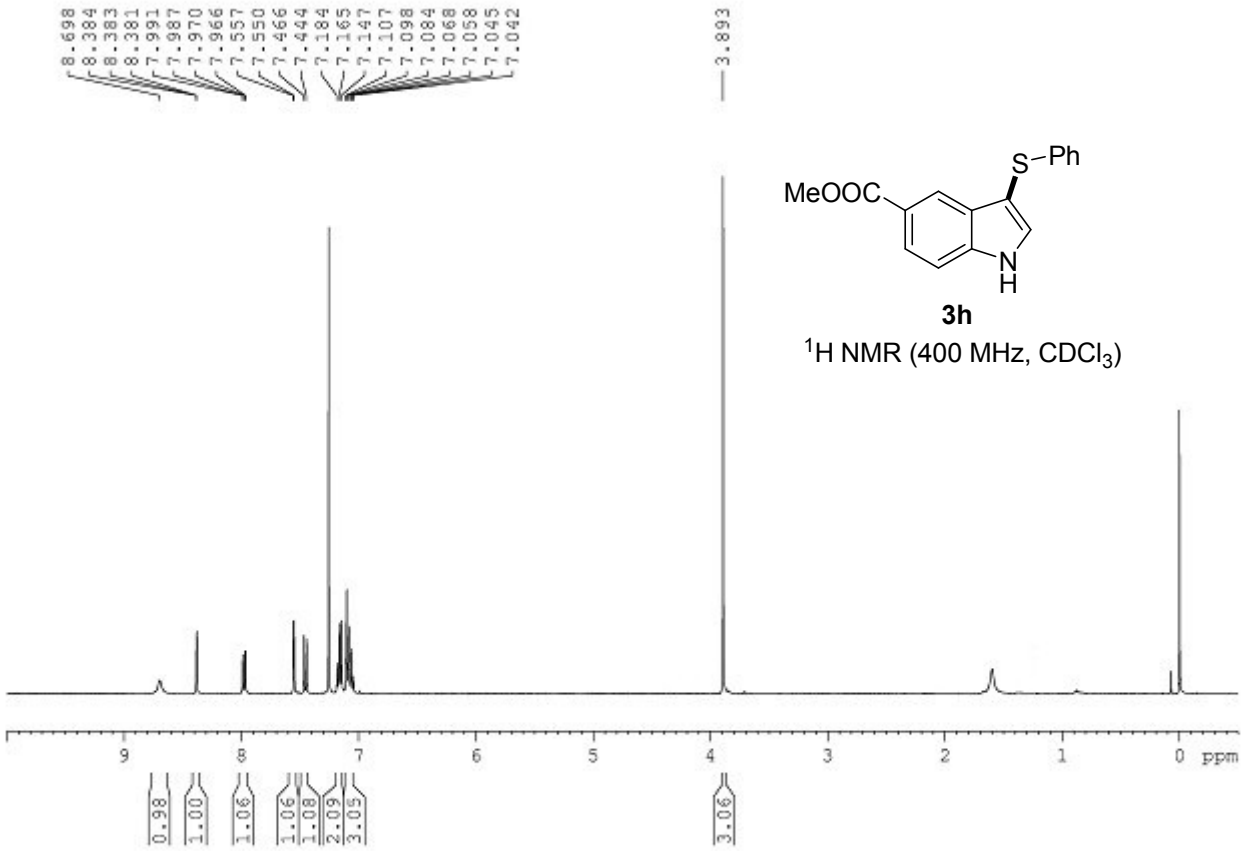
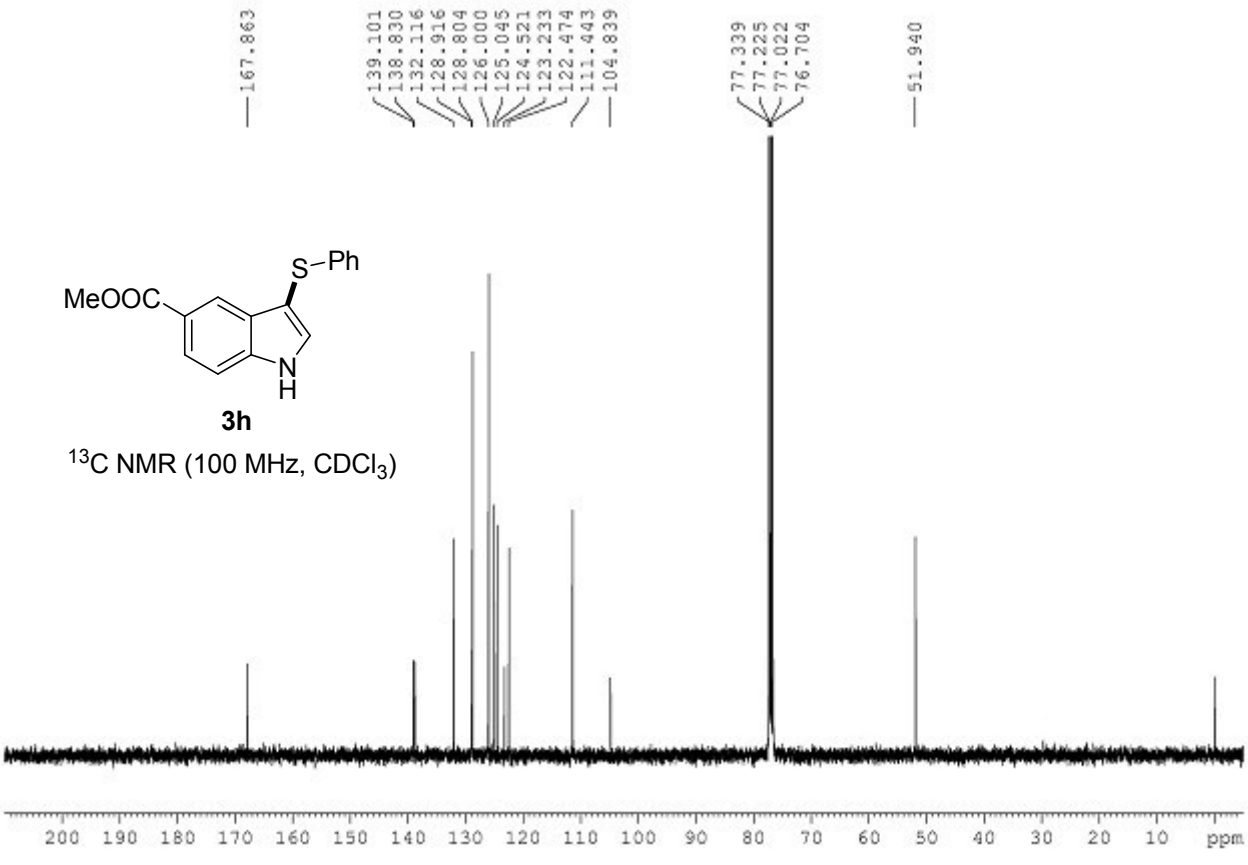


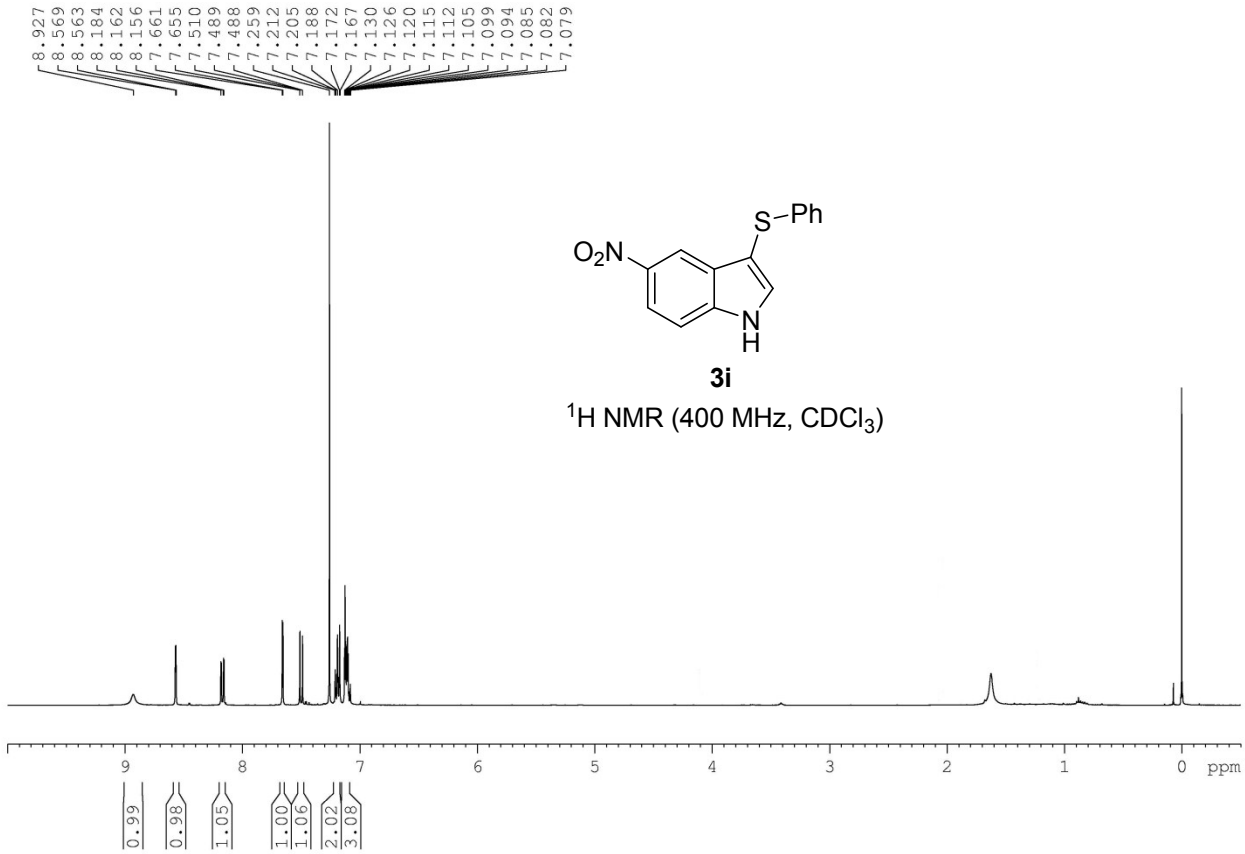
3h

^{1}H NMR (400 MHz, $CDCl_3$)



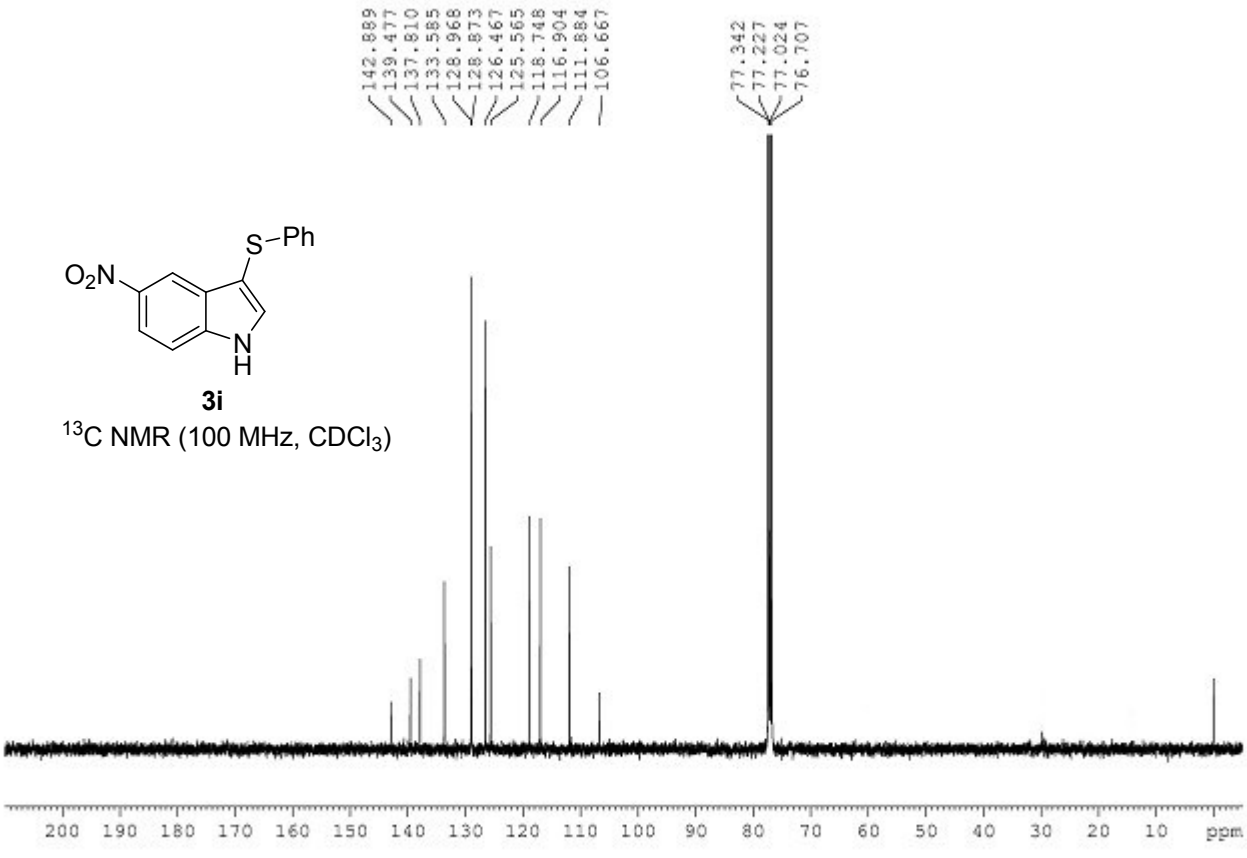
3h

^{13}C NMR (100 MHz, $CDCl_3$)



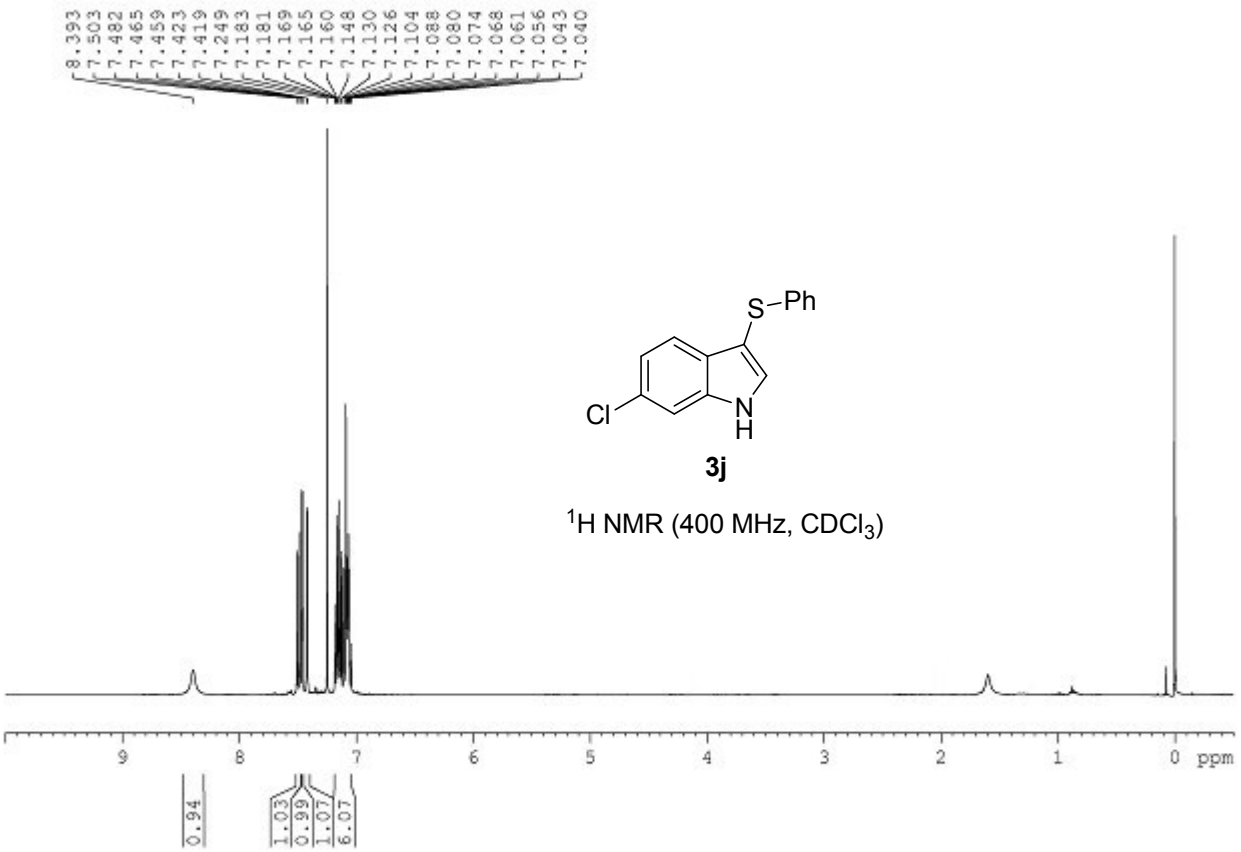
3i

^{1}H NMR (400 MHz, $CDCl_3$)



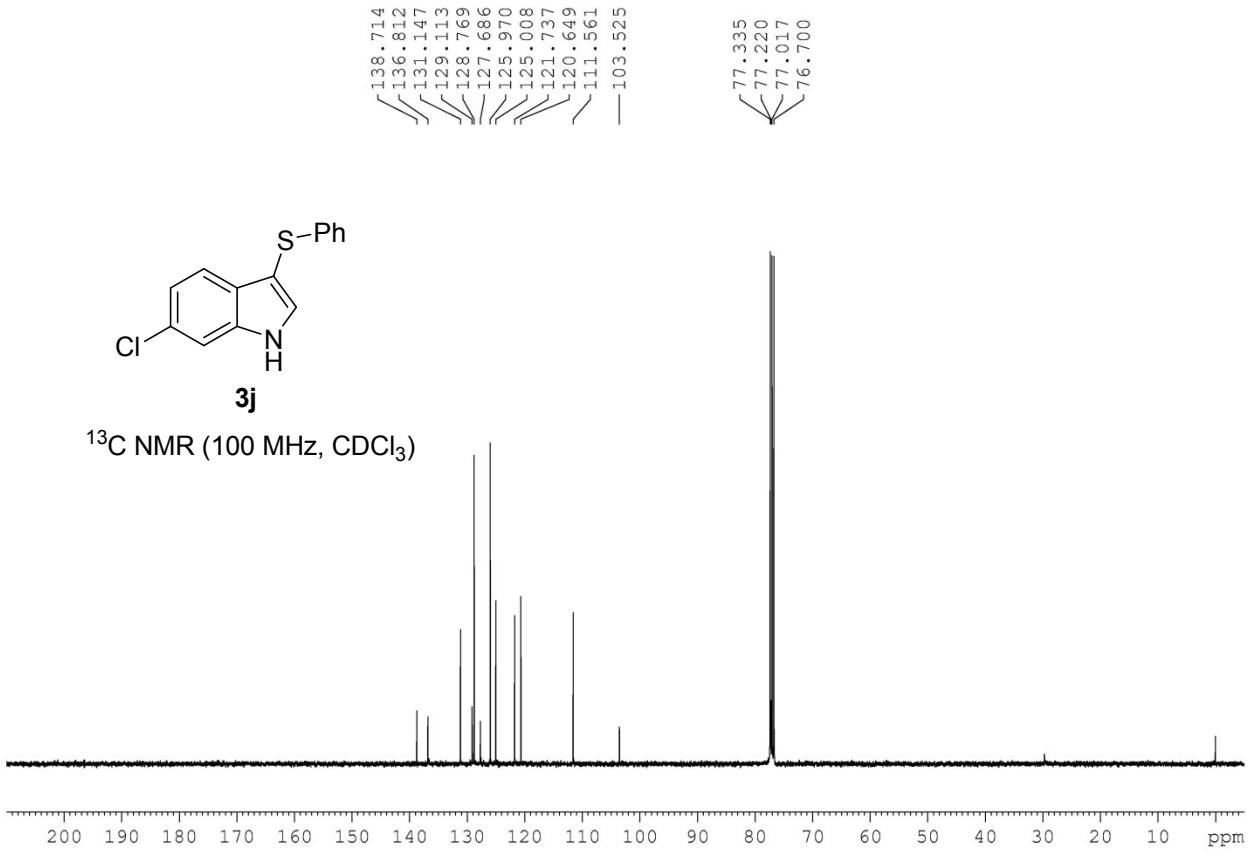
3i

^{13}C NMR (100 MHz, $CDCl_3$)



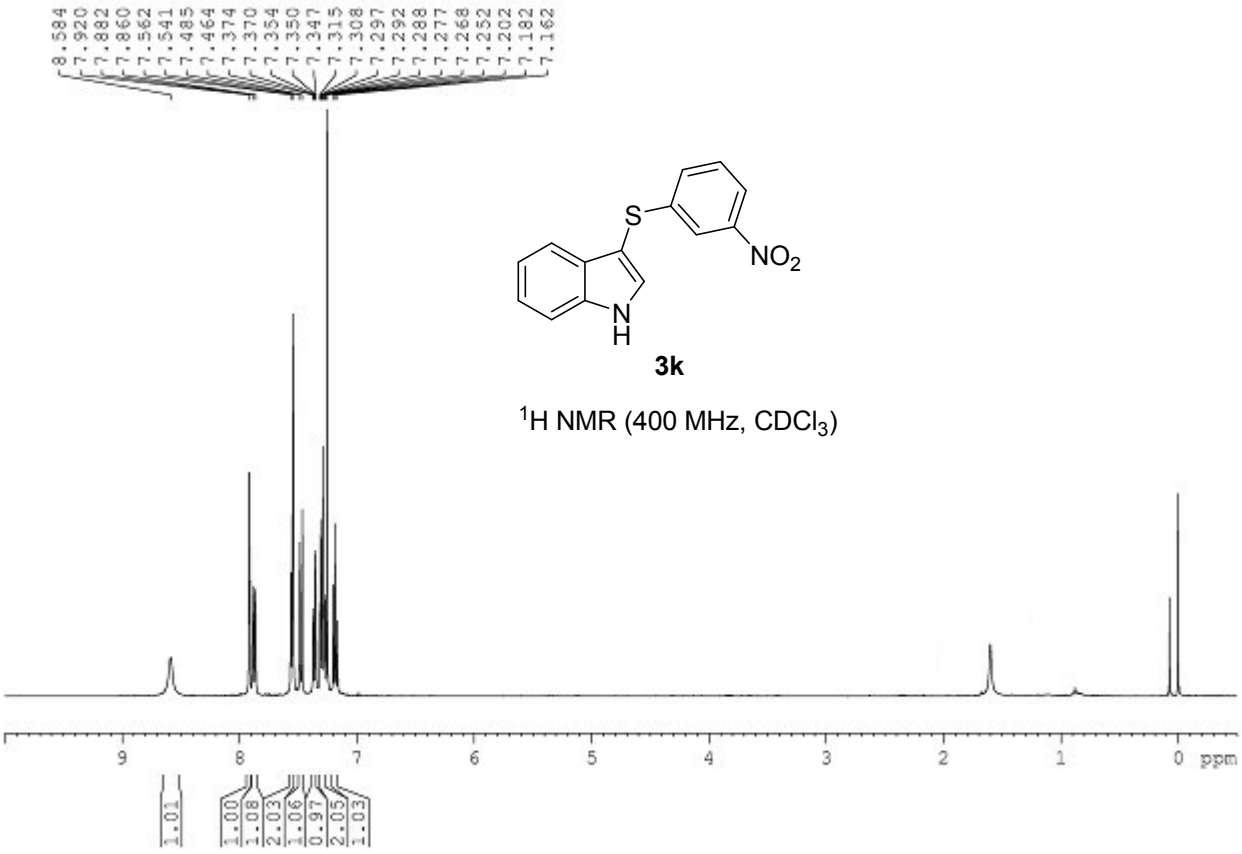
3j

^{1}H NMR (400 MHz, $CDCl_3$)



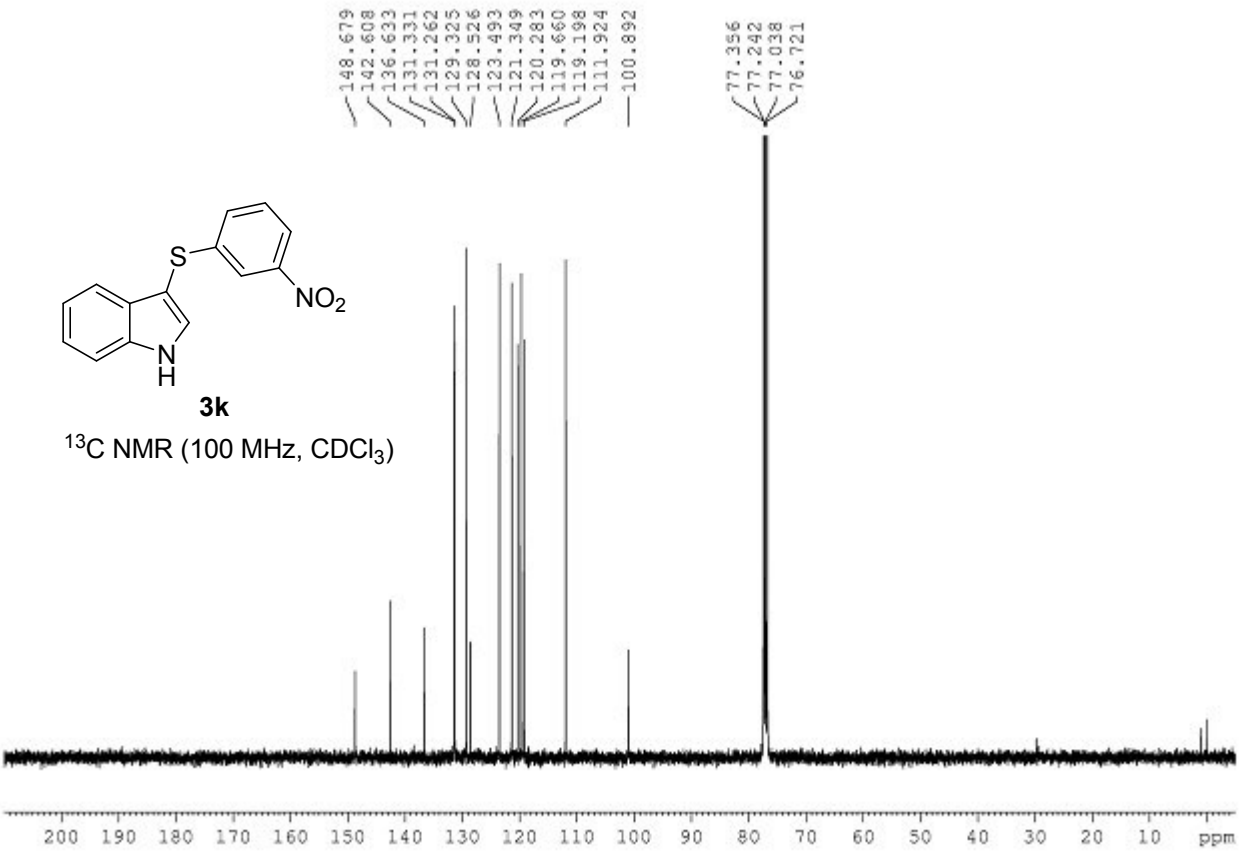
3j

^{13}C NMR (100 MHz, $CDCl_3$)



3k

^{1}H NMR (400 MHz, $CDCl_3$)



3k

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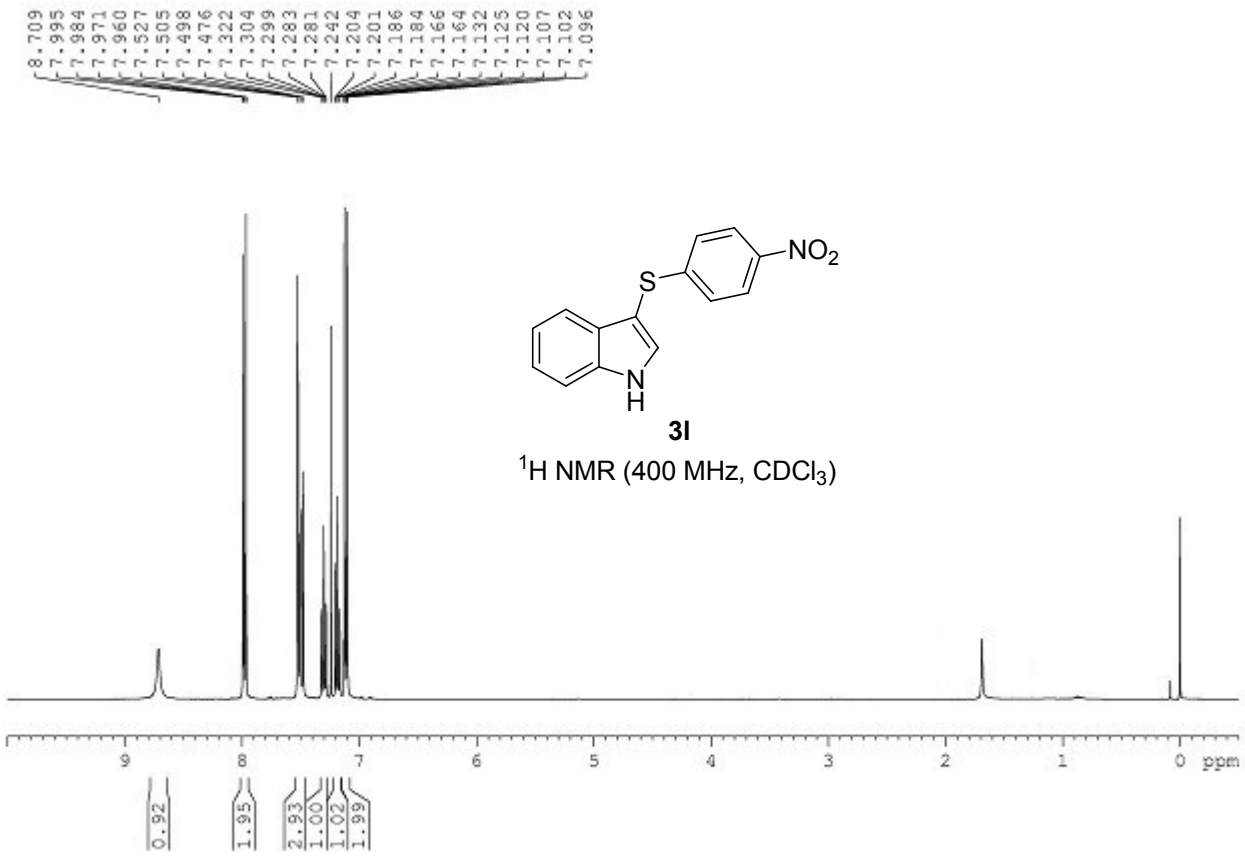
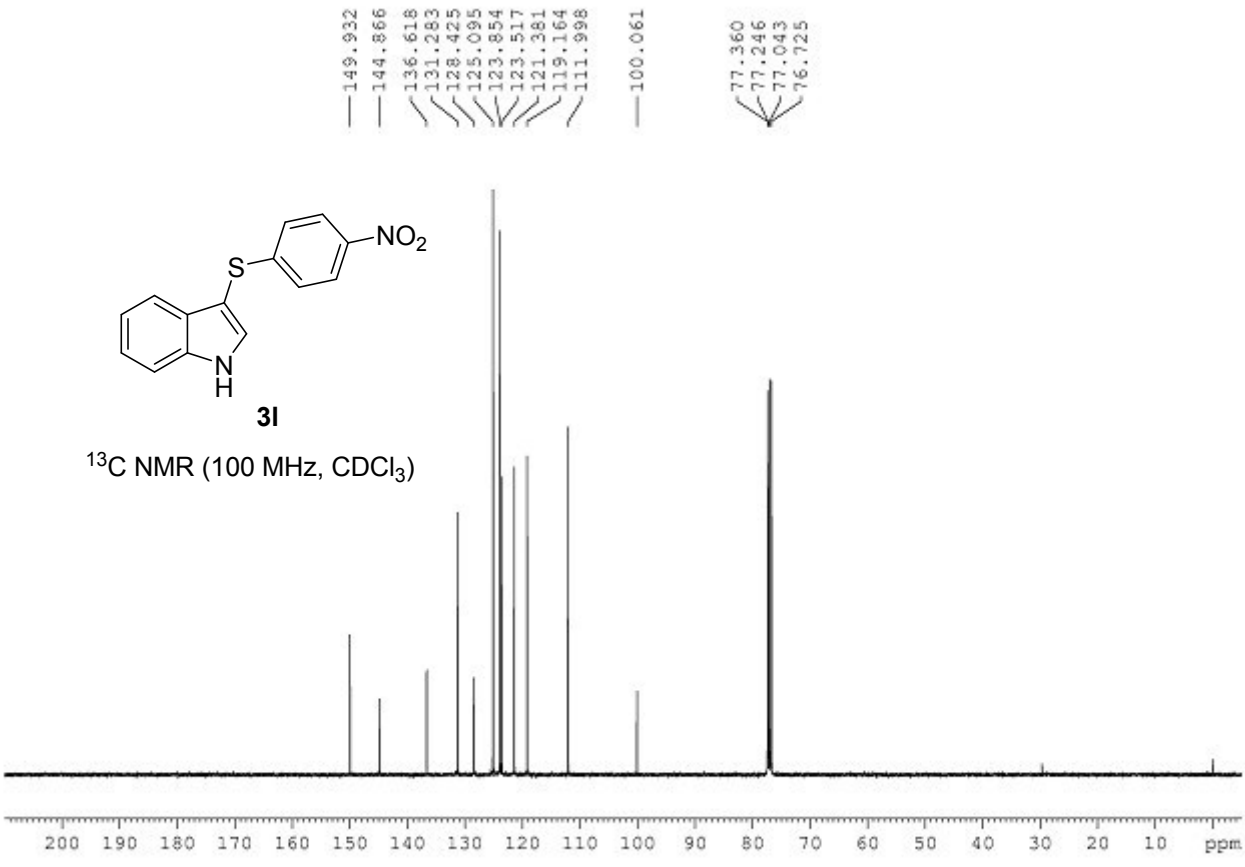


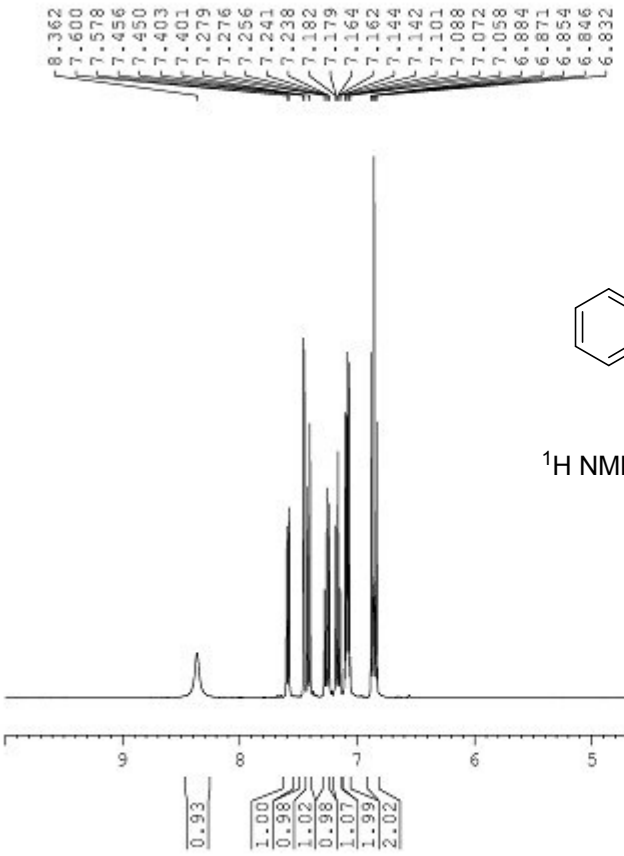
3l

^{1}H NMR (400 MHz, $CDCl_3$)



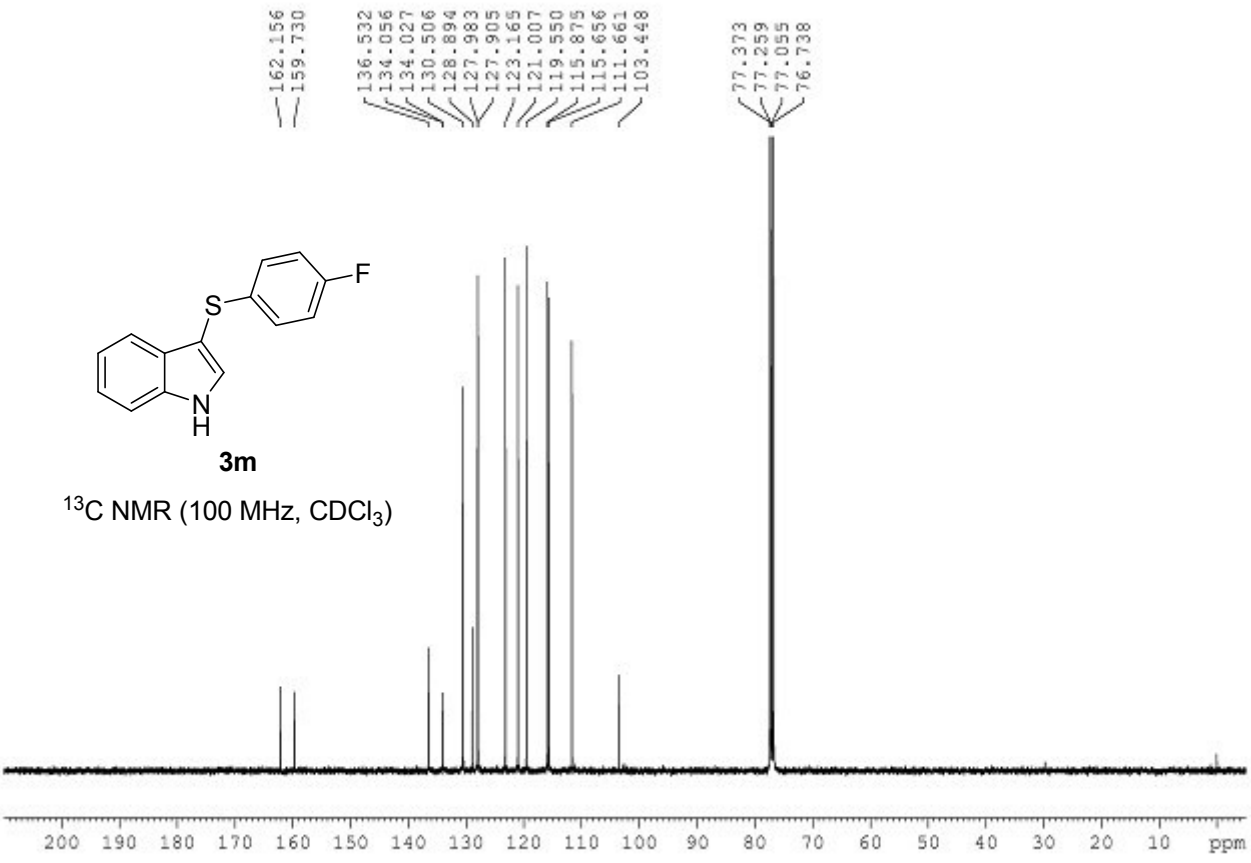
3l

^{13}C NMR (100 MHz, $CDCl_3$)



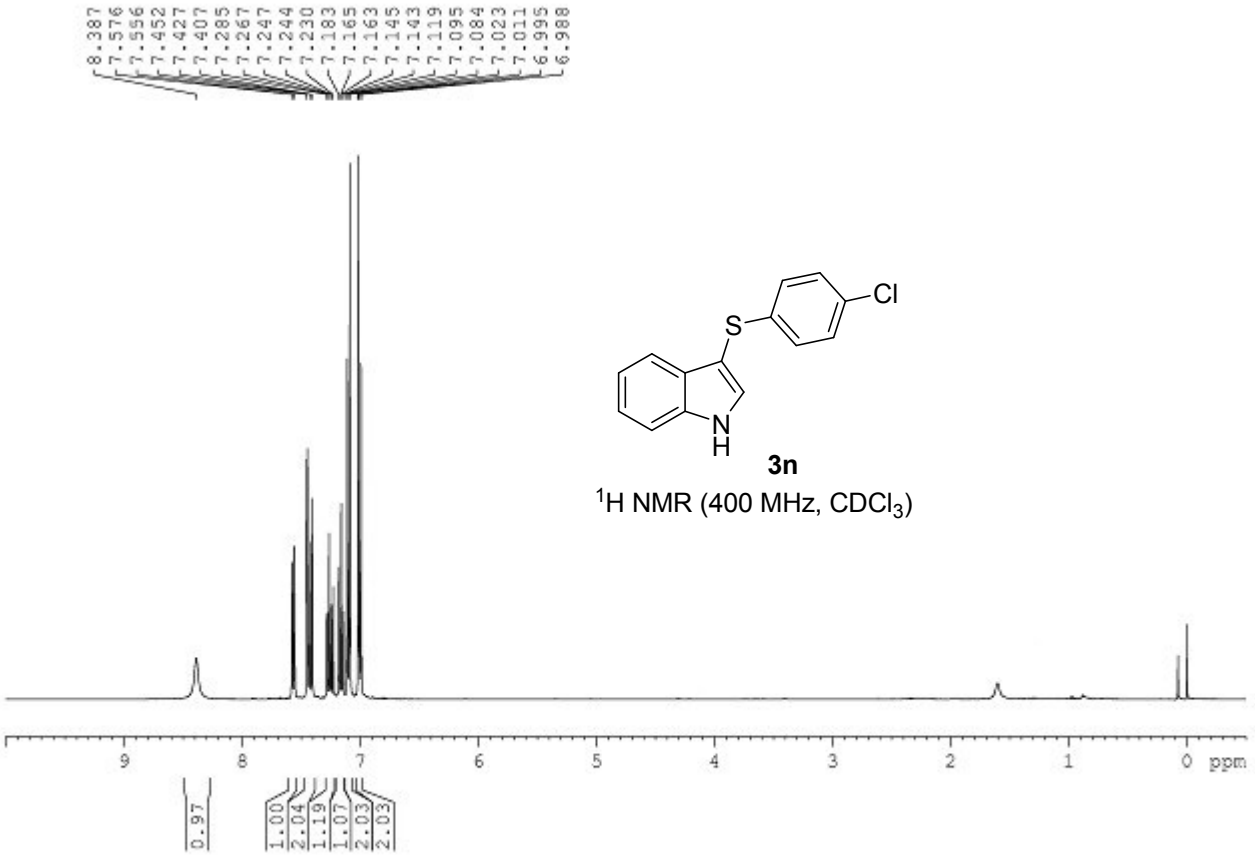
3m

^{1}H NMR (400 MHz, $CDCl_3$)



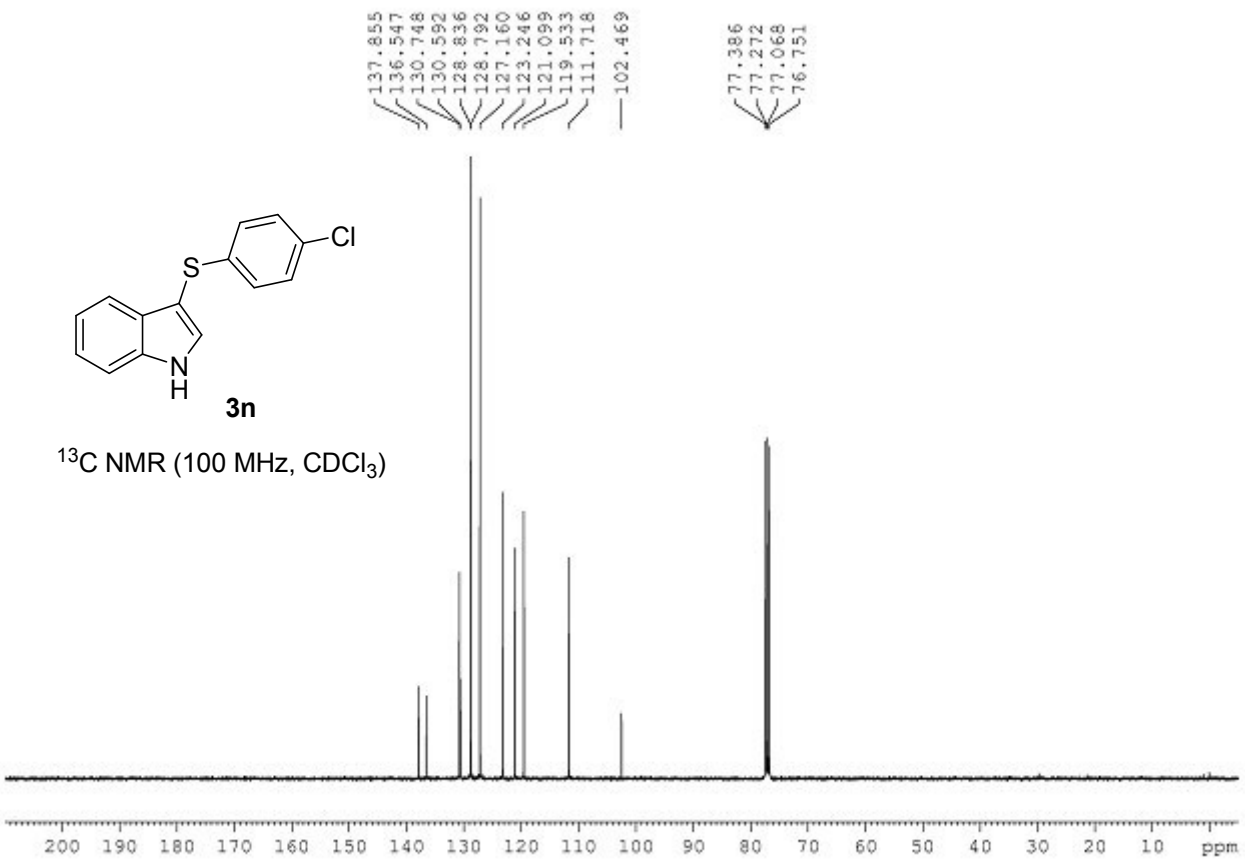
3m

^{13}C NMR (100 MHz, $CDCl_3$)



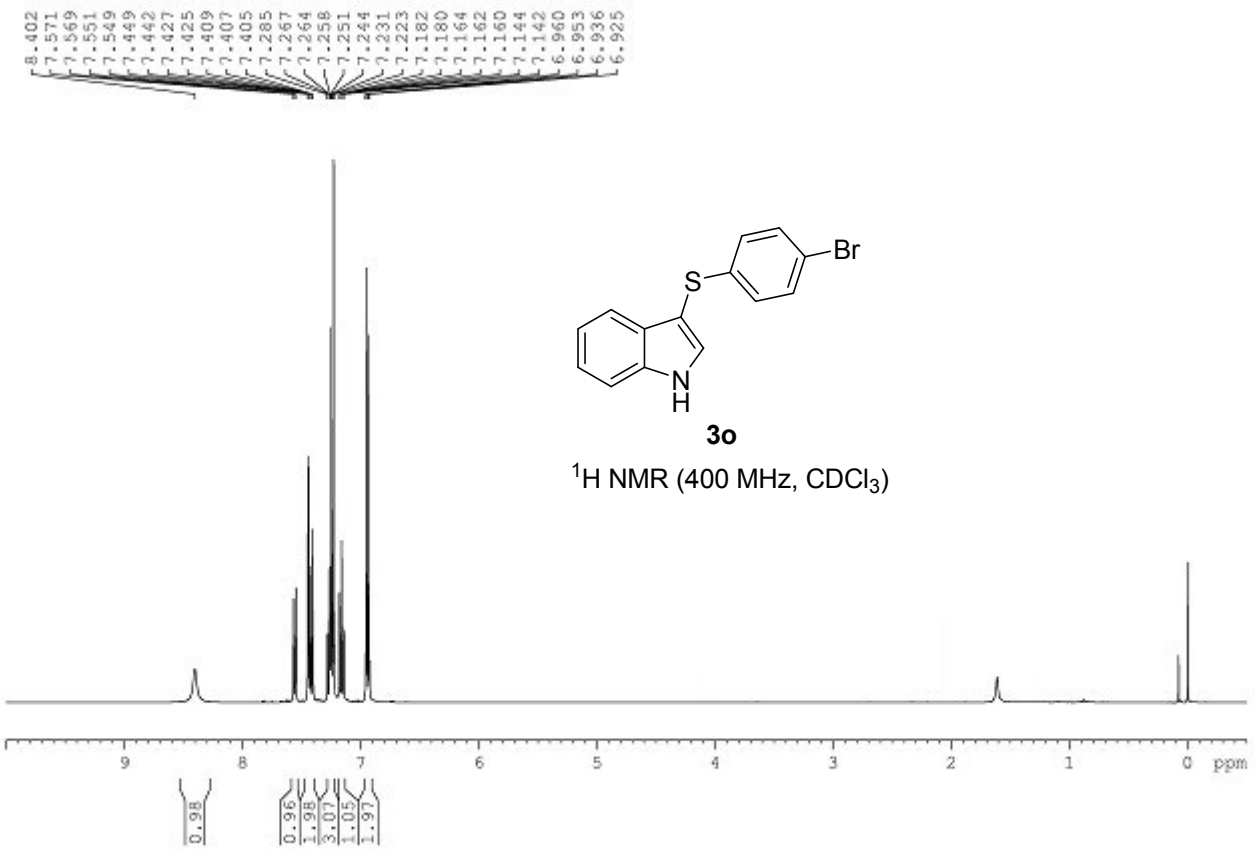
3n

^{1}H NMR (400 MHz, $CDCl_3$)



3n

^{13}C NMR (100 MHz, $CDCl_3$)



3o

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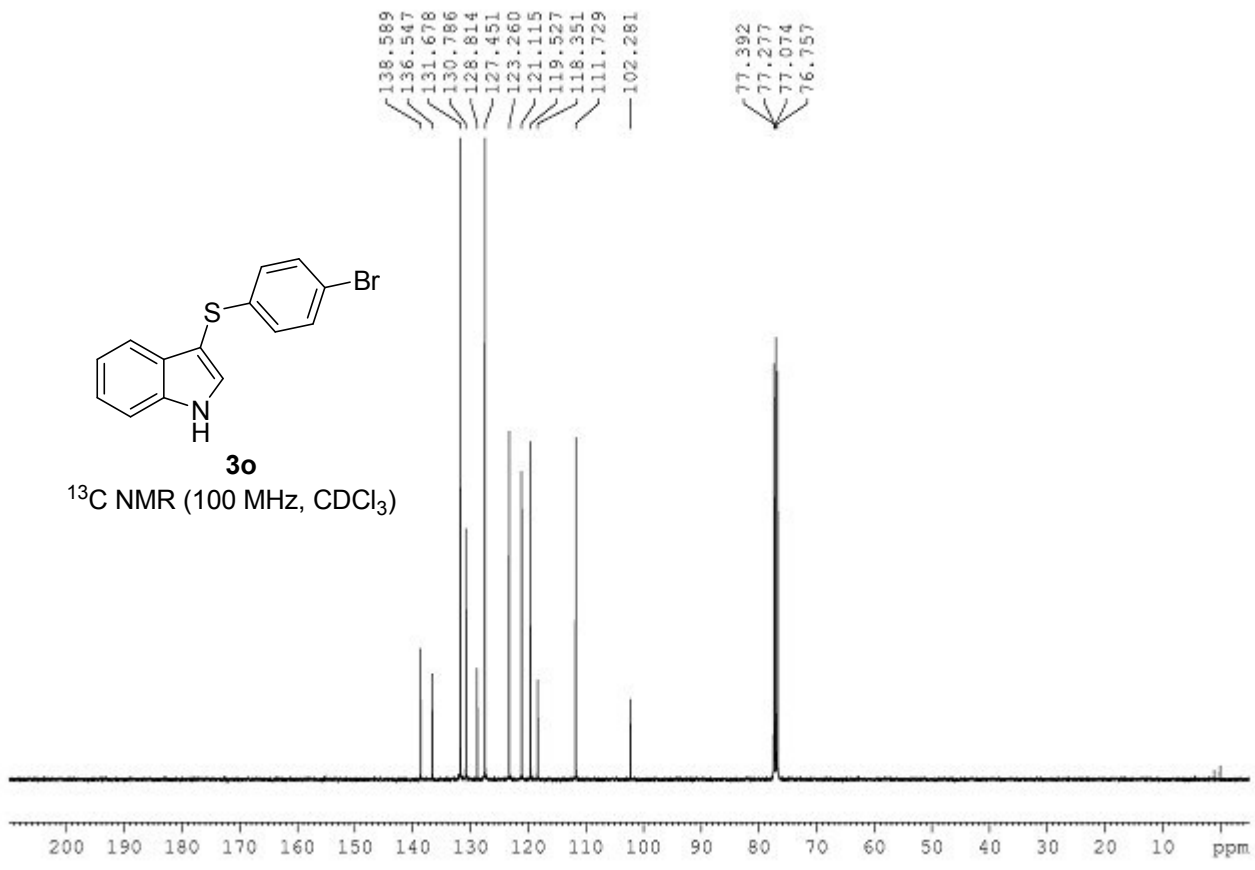

3o

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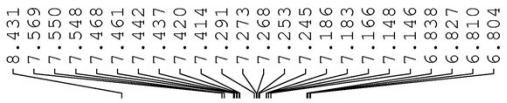
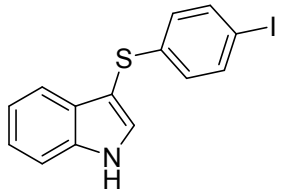
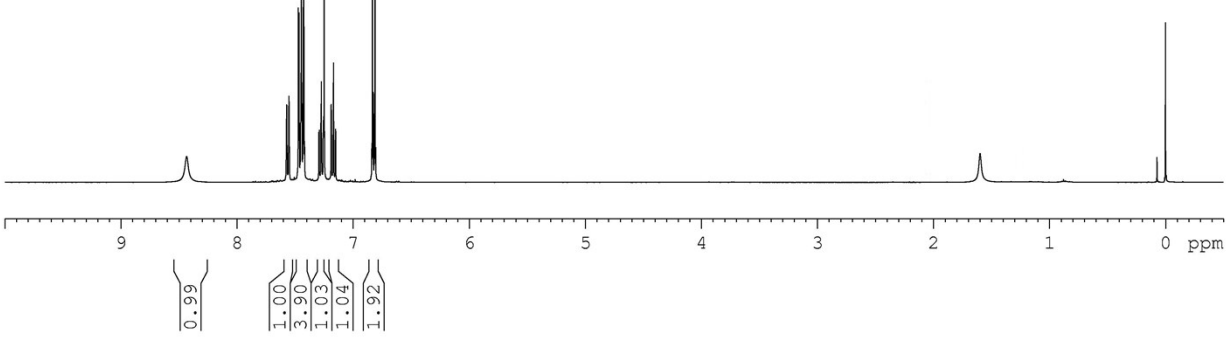
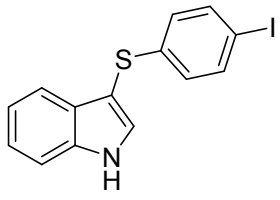




3p

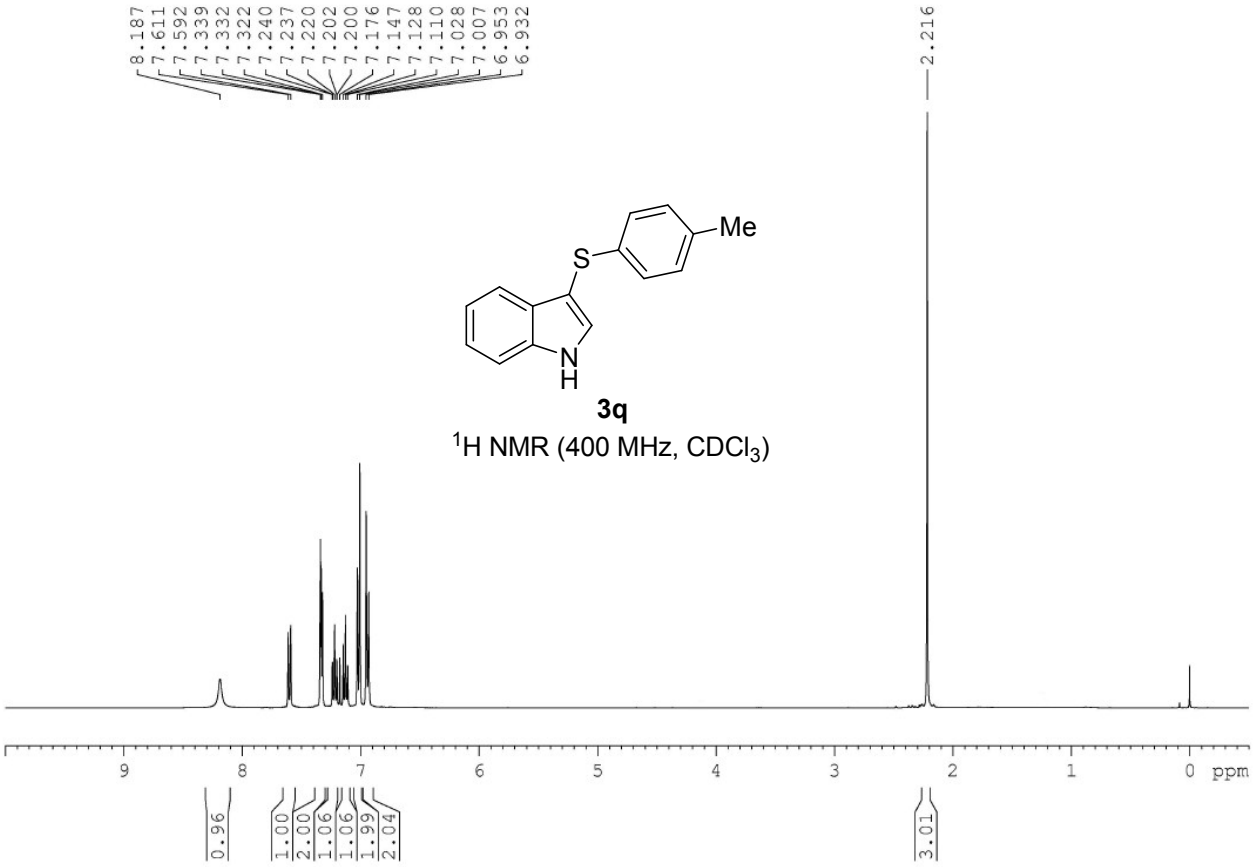
^{1}H NMR (400 MHz, $CDCl_3$)





3p

^{13}C NMR (100 MHz, $CDCl_3$)



3q

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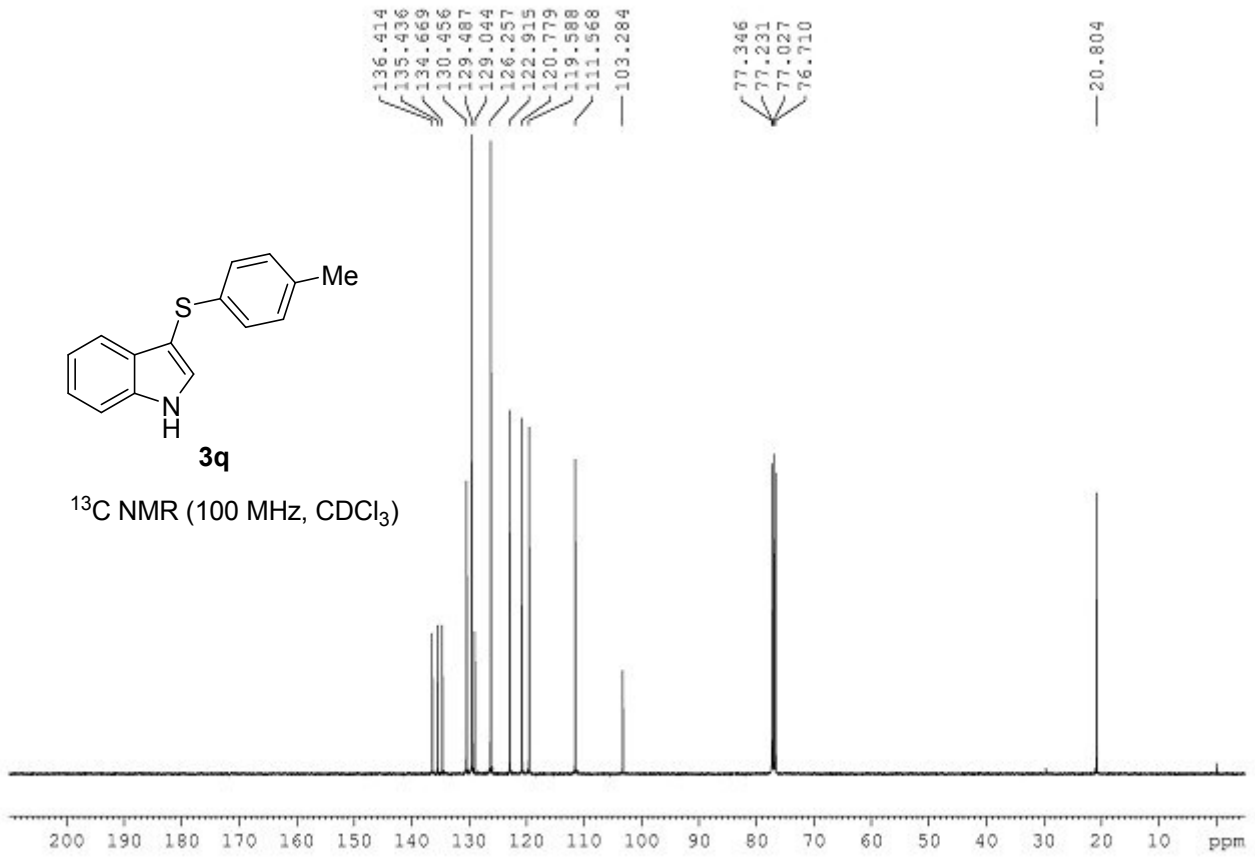
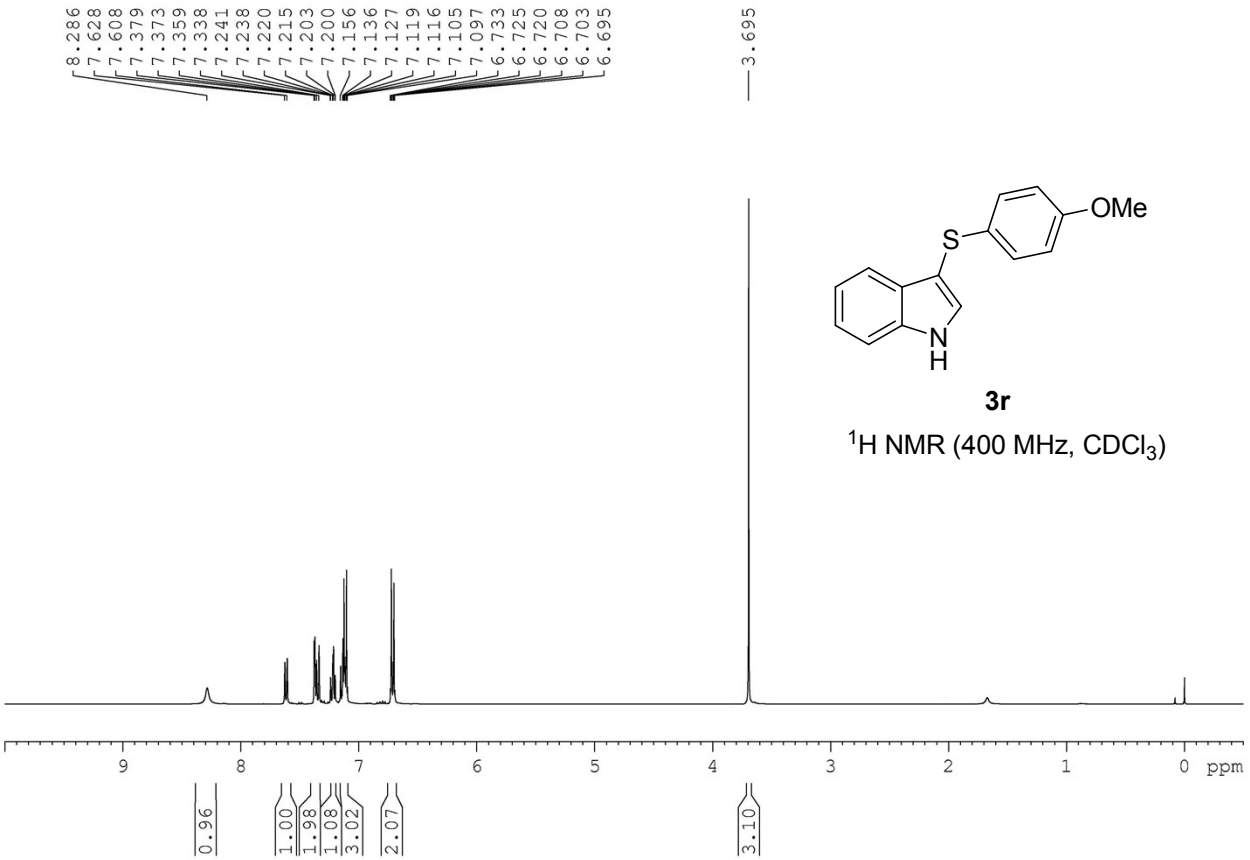


3q

^{13}C NMR (100 MHz, $CDCl_3$)



3r

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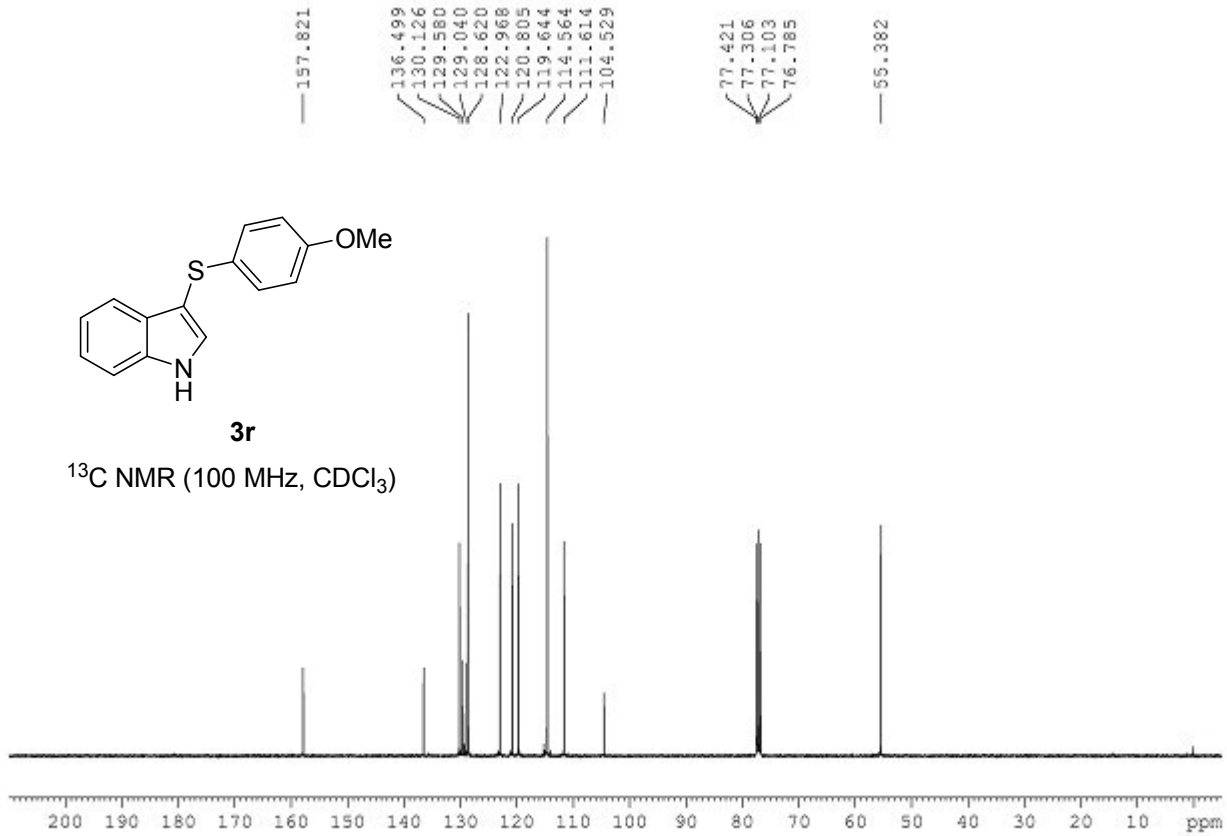

3r

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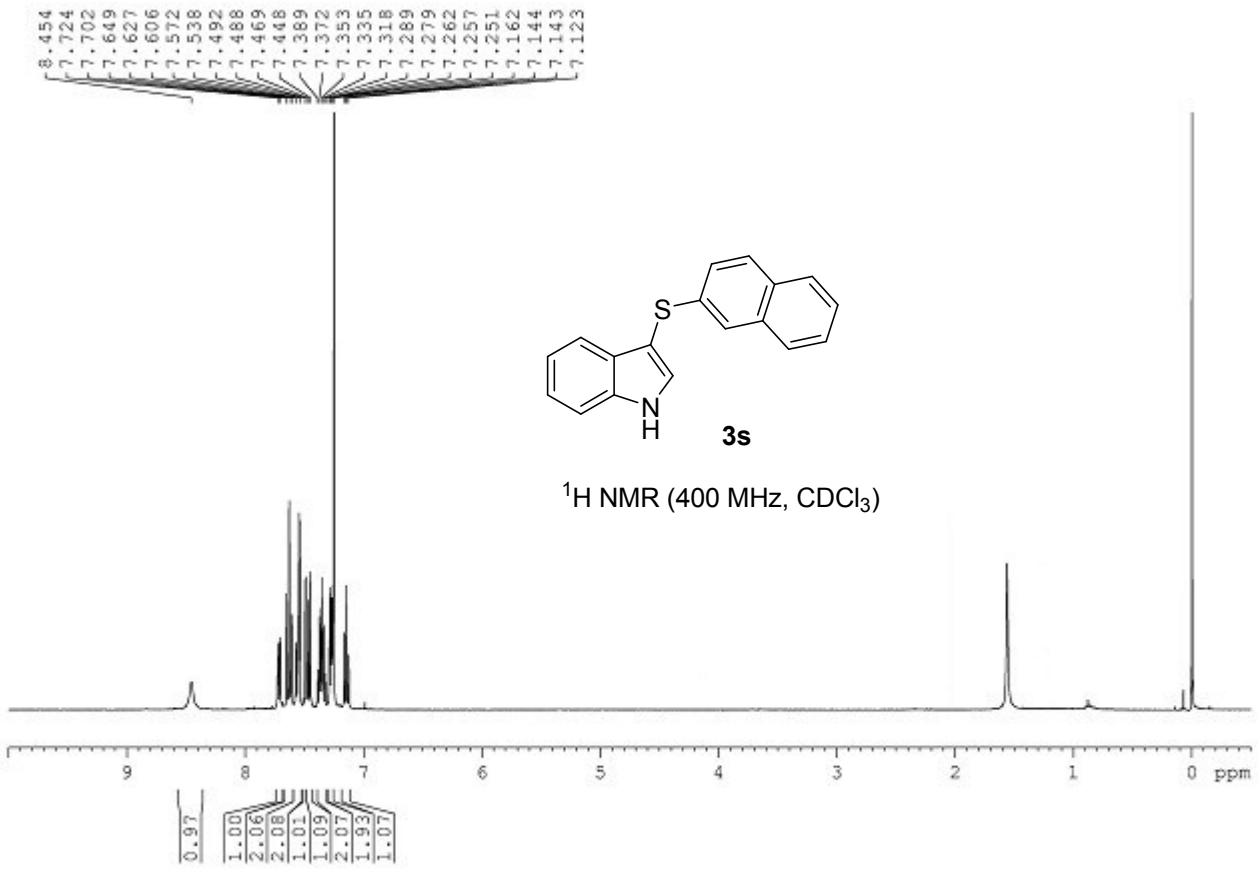

3s

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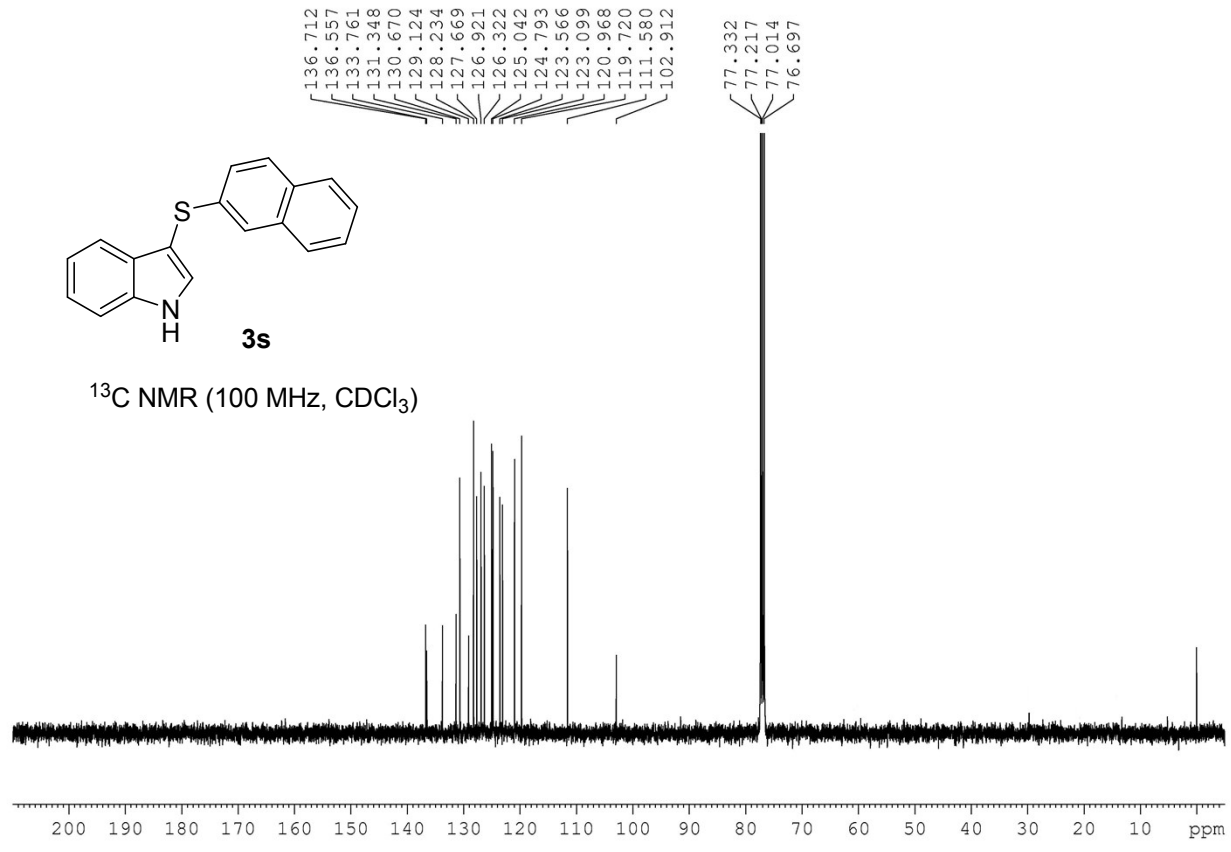

3s

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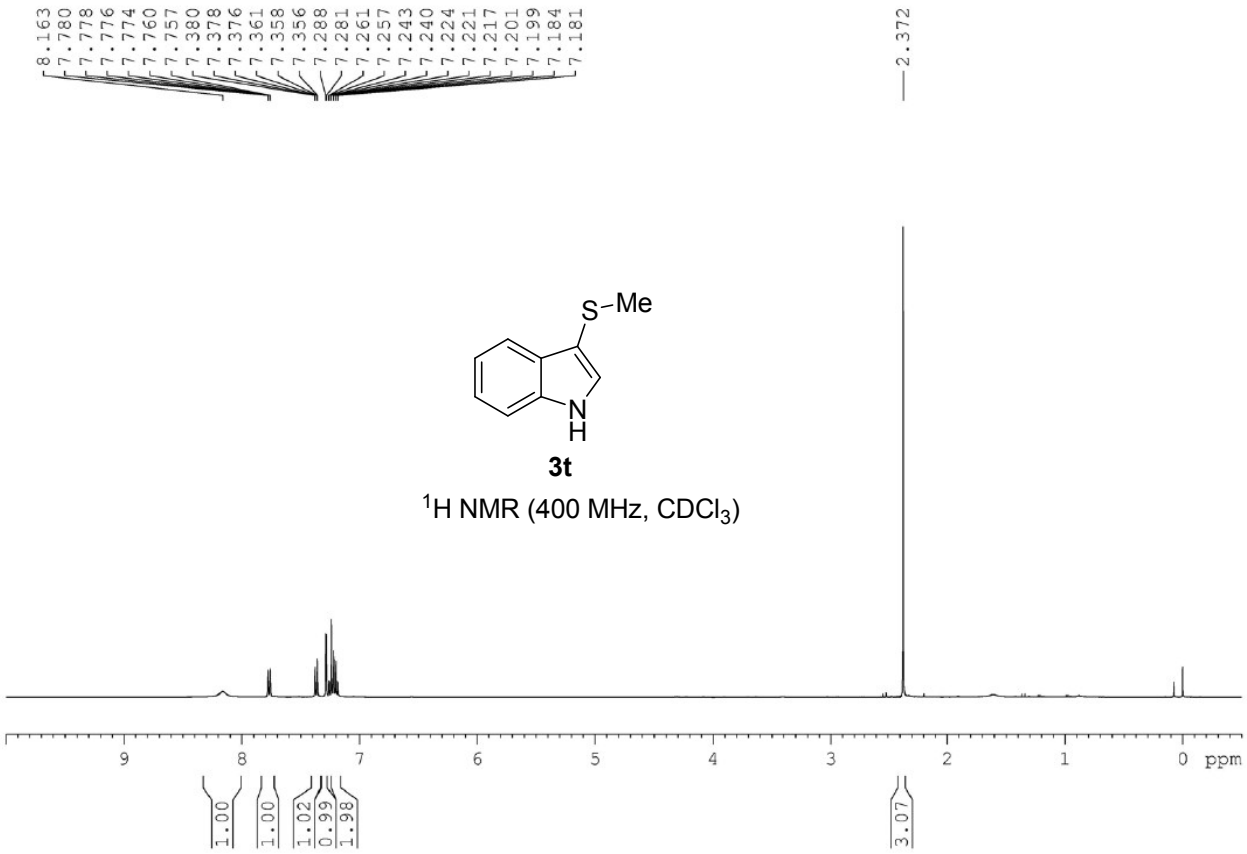
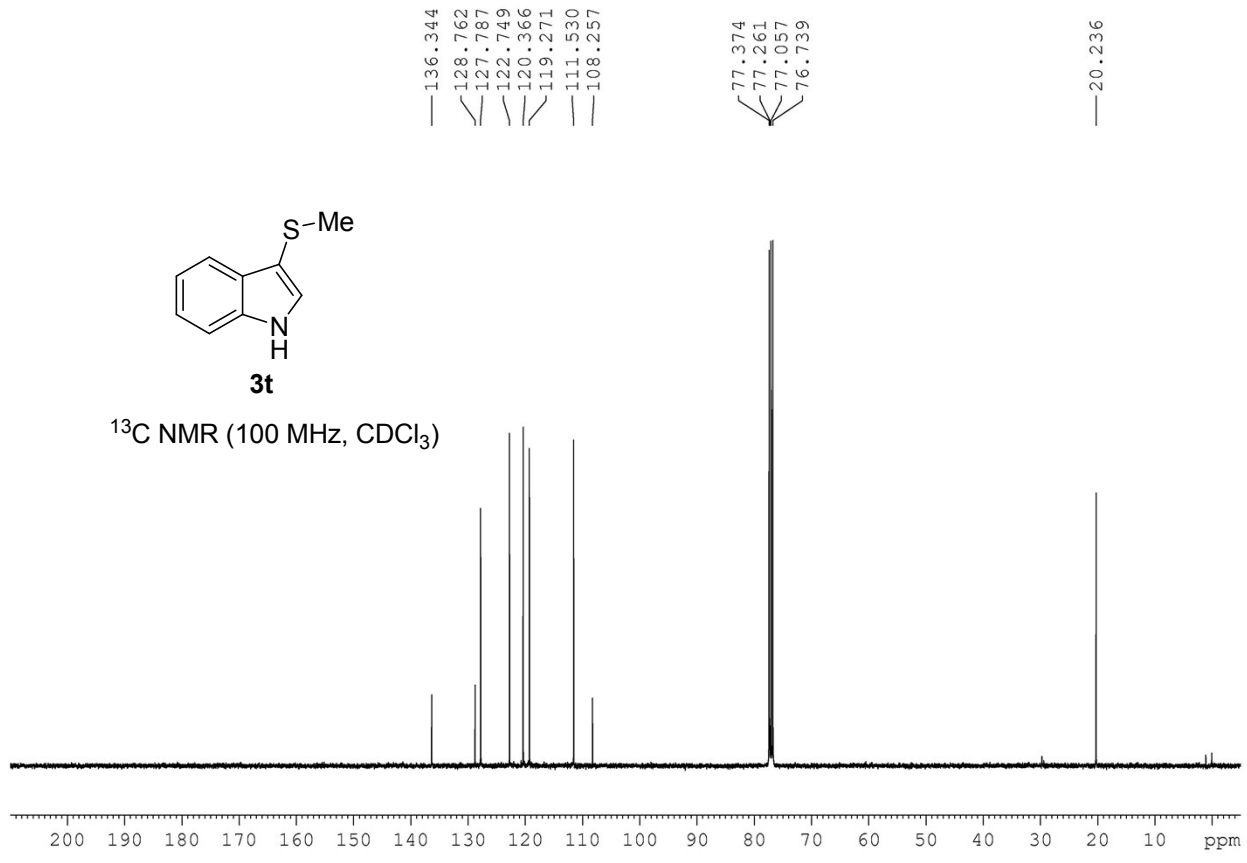


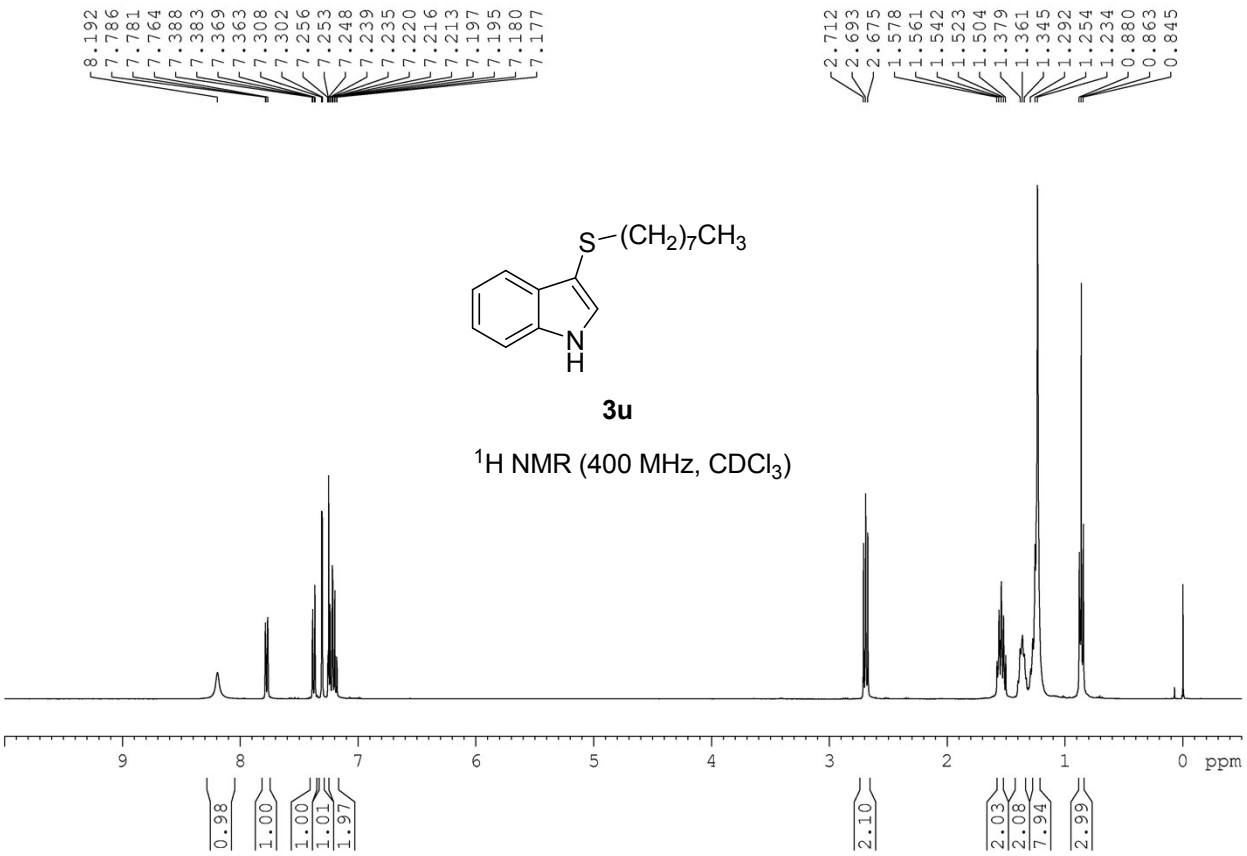
3t

^{1}H NMR (400 MHz, $CDCl_3$)



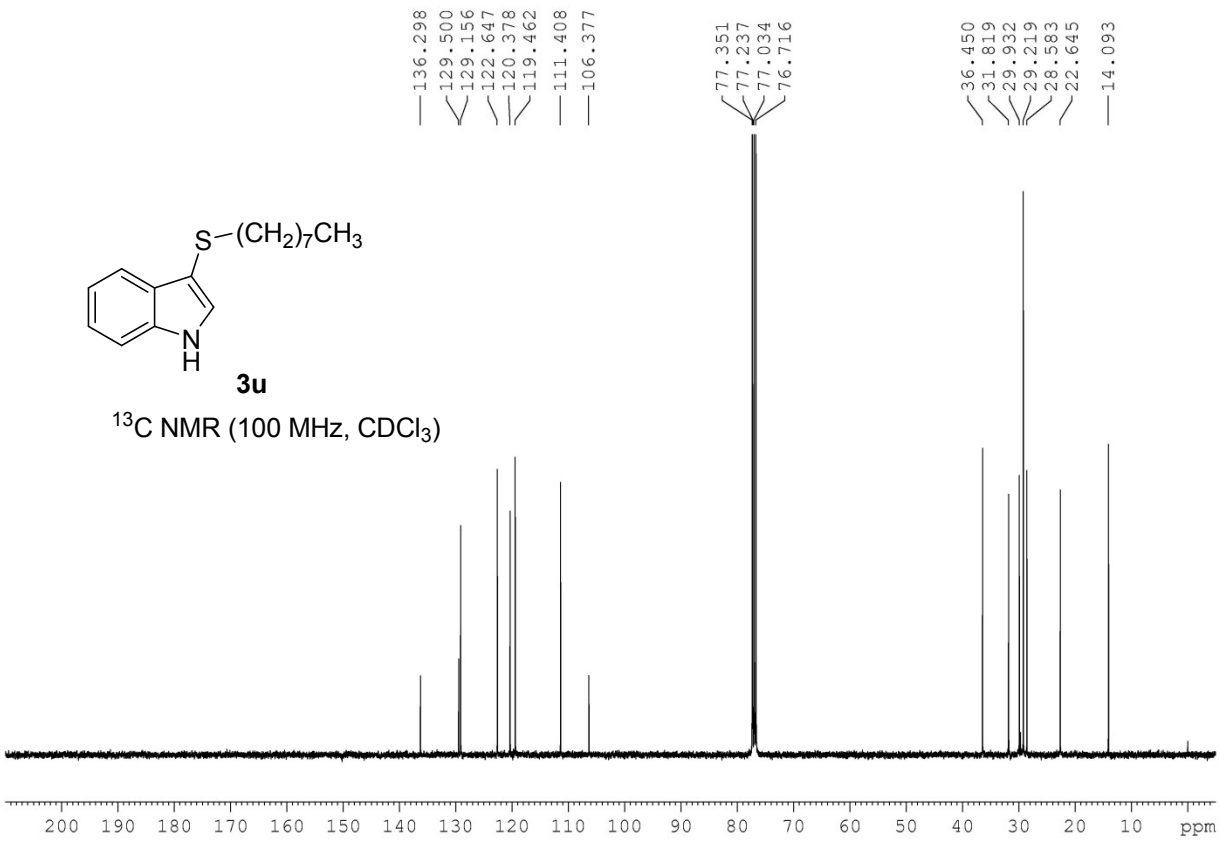
3t

^{13}C NMR (100 MHz, $CDCl_3$)



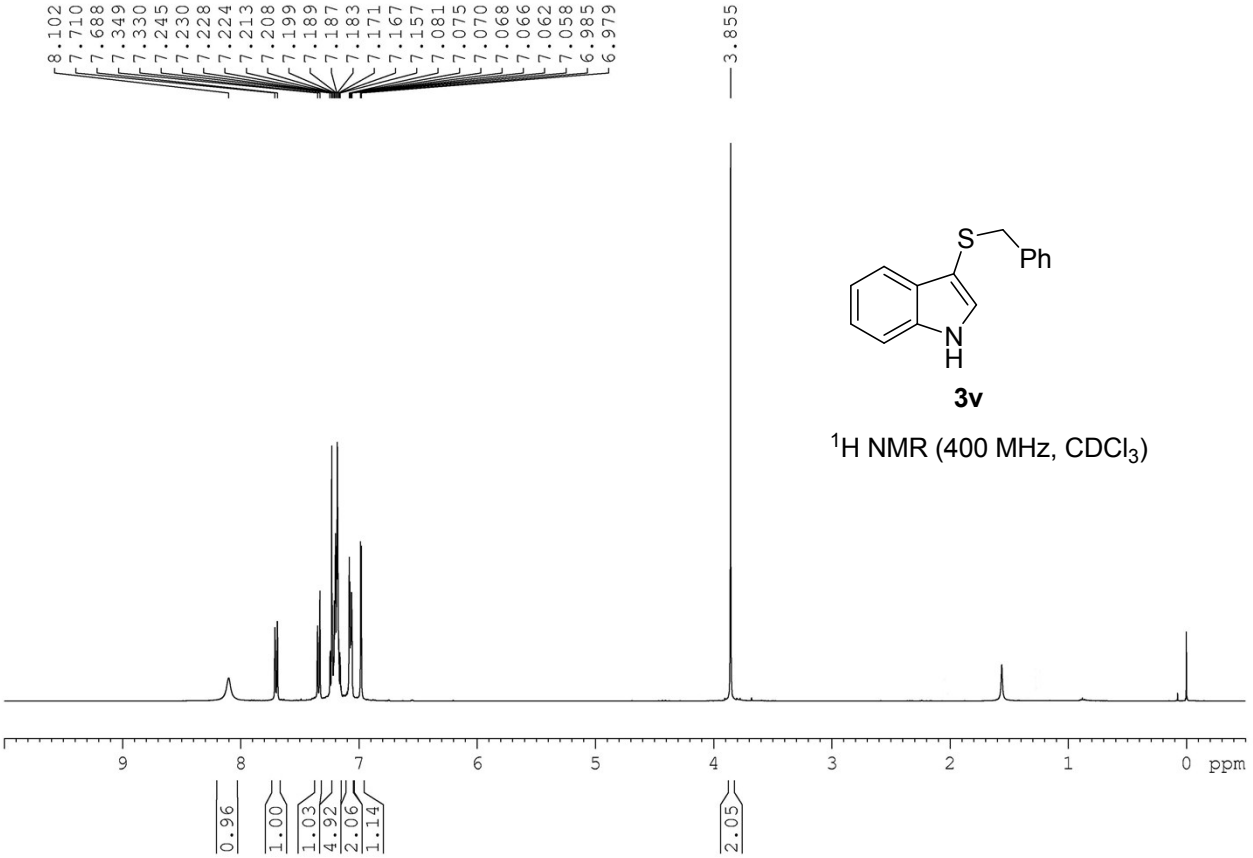
3u

^{1}H NMR (400 MHz, $CDCl_3$)



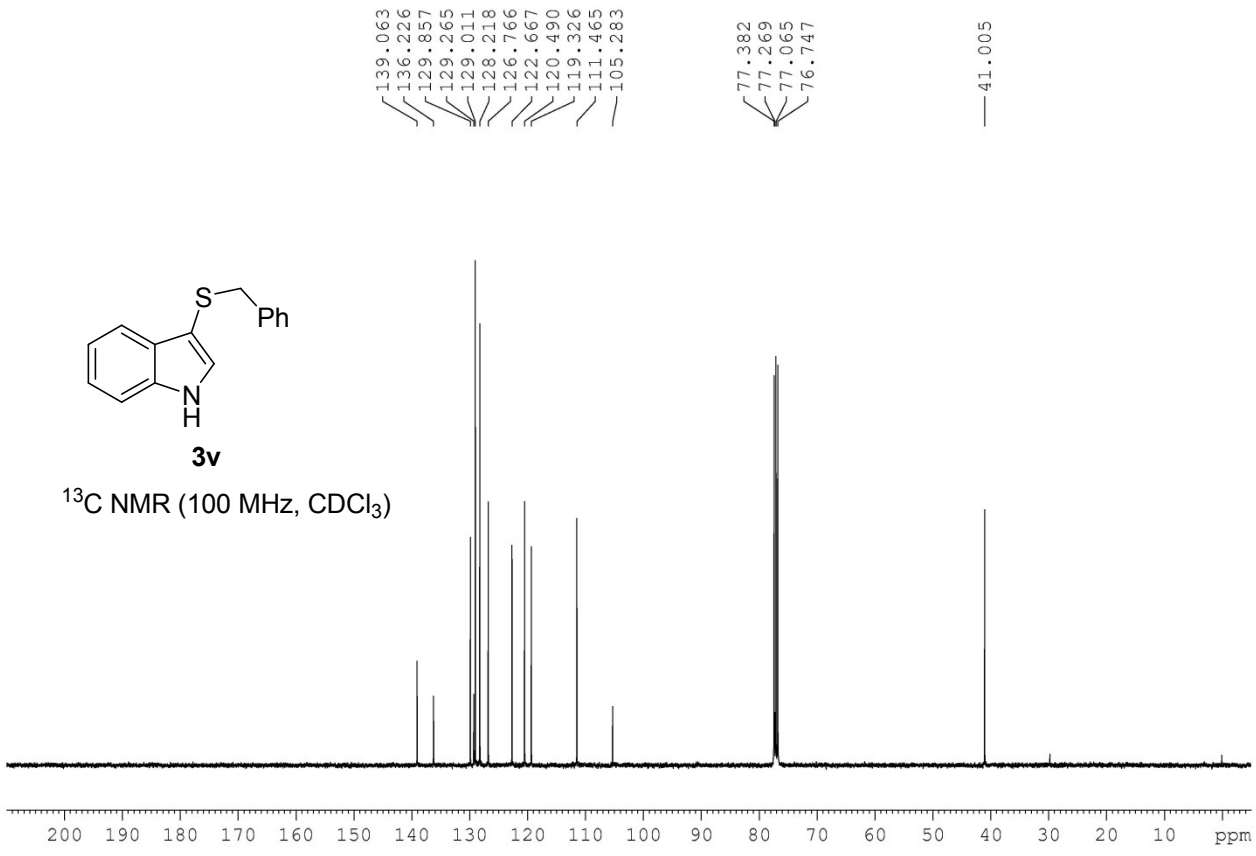
3u

^{13}C NMR (100 MHz, $CDCl_3$)



3v

^{1}H NMR (400 MHz, $CDCl_3$)



3v

^{13}C NMR (100 MHz, $CDCl_3$)