Electronic Supplementary Information

Synthesis of quinolines and naphthyridines via catalytic retro-aldol reaction of β-hydroxyketones with *ortho*-aminobenzaldehydes or nicotinaldehydes

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Contents

1. General experimental considerations:

All the reactants and reagents were used as received commercially without further purification unless otherwise noted. β-Hydroxy ketones **2b-e** were prepared according to a recent report by addition of ArMgX reagents to 1,3-diketones.[1] Except **1a, 1e, 1f, 1m** and **2-aminonicotinaldehyde**, the other *ortho*-amino benzaldehydes or nicotinaldehydes were prepared by a sequence of reduction of the corresponding *ortho*-amino benzoic acids with $LiAlH_4$ in THF, followed by oxidation of the resulting *ortho*-amino benzyl alcohols by MnO_2 in CH_2Cl_2.[2] All the reactions were performed under N_2 atmosphere which was realized through standard evacuation/back-fill technique after three times. ^{1}H NMR spectra were recorded on a 400 MHz spectrometer using $CDCl_3$ as the solvent; ^{13}C NMR spectra were recorded at 101 MHz; ^{19}F NMR spectra were at 376 MHz. Chemical shifts were referenced to TMS or residual solvent peak as the internal standard. Coupling constants for fine splitting of signals were reported in Hertz where applicable. Analytic elemental analyses were performed using Elementar VARIOEL III. Gas chromatography analyses were performed using GC9790II. IR spectra were recorded on a FT-IR spectrometer.

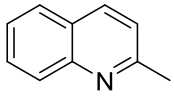
2. Experimental procedures and characterization data for all the products

2.1 Procedure for the synthesis of quinolines (3) and naphthyridines (4):

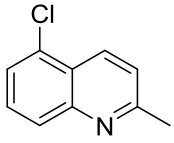
IPrCuCl (6.0 mg, 0.012 mmol) and NaO*t*Bu (6 mg, 0.062 mmol) were placed in an oven-dried 25-mL Schlenk tube equipped with a magnetic stir bar. The tube was sealed, evacuated and backfilled with nitrogen three times. To the flask was then

added by syringe a solution of β-hydroxy ketone **2a** (2.0 mmol) or other β-hydroxy ketone (1.0 mmol) and 2-aminobenzaldehyde or 2-aminonicotinaldehyde (**1**, 0.50 mmol) in toluene (3.0 mL). The contents in the tube were stirred at 70^{o}C (oil bath) for 3 h. After the mixture was cooled to room temperature, ethyl acetate (5 mL) was added. After filtration, the filtrate was washed by brine (5 mL) and layered. The organic layer was separated and the aqueous layer was extracted twice with ethyl acetate (5 mL). The combined organic layers were dried over Na_2SO_4 and then evaporated under vacuum to extrude organic solvents. The resulting residue was purified by column chromatography on silica gel (eluent: petroleum ether/ ethyl acetate = 10:1~5:1 (v/v)) to provide pure products **3** and **4**.

2.2 Characterization data for all the products

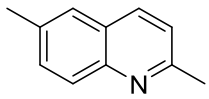


2-Methylquinoline (**3a**; 65 mg, 91%).[3] Yellow liquid; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.10 – 8.02 (m, 2H), 7.79 (d, *J* = 7.9 Hz, 1H), 7.70 (t, *J* = 7.4 Hz, 1H), 7.50 (t, *J* = 7.3 Hz, 1H), 7.31 (d, *J* = 8.3 Hz, 1H), 2.77 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 159.0, 147.8, 136.2, 129.4, 128.6, 127.5, 126.5, 125.7, 122.0, 25.3.

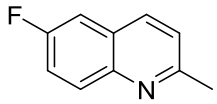


5-Chloro-2-methylquinoline (**3b**; 82 mg, 93%).[4] Yellow solid; mp 48-50 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.42 (d, *J* = 8.6 Hz, 1H), 7.94 (d, *J* = 8.1 Hz, 1H), 7.63 –

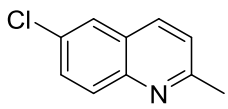
7.50 (m, 2H), 7.35 (d, J = 8.6 Hz, 1H), 2.75 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 159.8, 148.5, 132.9, 131.2, 129.1, 127.8, 125.8, 124.6, 122.8, 25.2. Anal Calcd for $C_{10}H_8ClN$: C, 67.62; H, 4.54. Found: C, 67.75; H, 4.43.



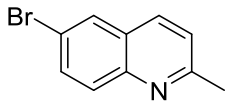
2,6-Dimethylquinoline (**3c**; 77 mg, 98 %).[5] Orange solid; mp 55-56 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.93 (m, 2H), 7.51 (d, J = 7.3 Hz, 2H), 7.23 (dd, J = 8.4, 1.4 Hz, 1H), 2.73 (s, 3H), 2.51 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 157.9, 146.4, 135.5, 135.3, 131.6, 128.3, 126.5, 126.4, 121.9, 25.2, 21.4.Anal Calcd for $C_{11}H_{11}N$: C, 84.04; H, 7.05. Found: C, 84.13; H, 6.93.



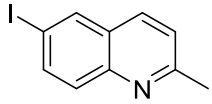
6-Fluoro-2-methylquinoline (**3d**; 76 mg, 94%).[6] Yellow solid; mp 52-54 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.04 – 7.98 (m, 2H), 7.48 – 7.42 (m, 1H), 7.39 (dd, J = 8.8, 2.8 Hz, 1H), 7.30 (d, J = 8.4 Hz, 1H), 2.74 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ160.0 (d, J = 246.6 Hz), 158.3 (d, J = 2.7 Hz), 144.9 (s), 135.5 (d, J = 5.2 Hz), 131.0 (d, J = 9.0 Hz), 127.0 (d, J = 9.9 Hz), 122.7 (s), 119.4 (d, J = 25.6 Hz), 110.5 (d, J = 21.6 Hz), 25.2 (s). ^{19}F NMR (376 MHz, $CDCl_3$) δ -114.97. Anal Calcd for $C_{10}H_8FN$: C, 74.52; H, 5.00. Found: C, 74.39; H, 5.13.



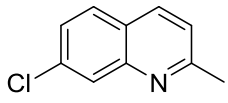
6-Chloro-2-methylquinoline (**3e**; 83 mg, 94%).[3] Orange solid; mp 82-83 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.95 (dd, *J* = 8.6, 3.5 Hz, 2H), 7.74 (d, *J* = 2.2 Hz, 1H), 7.61 (dd, *J* = 9.0, 2.3 Hz, 1H) 7.30 (d, *J* = 8.5 Hz, 1H), 2.74 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 159.3, 146.2, 135.2, 131.3, 130.2, 127.1, 126.1, 122.9, 25.3. Anal Calcd for $C_{10}H_8ClN$: C, 67.62; H, 4.54. Found: C, 67.75; H, 4.41.



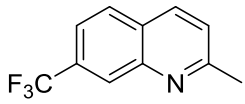
6-Bromo-2-methylquinoline (**3f**; 102 mg, 92%).[6] Orange solid; mp 96-97 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.86 (t, *J* = 9.0 Hz, 3H), 7.70 (d, *J* = 8.8 Hz, 1H), 7.24 (d, *J* = 8.4 Hz, 1H), 2.70 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 159.5, 146.4, 135.1, 132.7, 130.4, 129.5, 127.5, 122.8, 119.3, 25.3. Anal Calcd for $C_{10}H_8BrN$: C, 54.08; H, 3.63. Found: C, 54.15; H, 3.57.



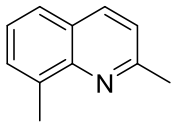
6-Iodo-2-methylquinoline (**3g**; 91 mg, 68%).[7] Yellow solid; mp 99-101 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.15 (d, *J* = 1.9 Hz, 1H), 7.94 – 7.89 (m, 2H), 7.75 (d, *J* = 8.9 Hz, 1H), 7.30–7.28 (m, 1H), 2.74 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 159.7, 146.8, 138.1, 136.2, 134.9, 130.4, 128.2, 122.7, 90.8, 25.4. Anal Calcd for $C_{10}H_8IN$: C, 44.64; H, 3.00. Found: C, 44.75; H, 3.08.



7-Chloro-2-methylquinoline (**3h**; 80 mg, 90%).[6] Yellow solid; mp 75-76 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.03 (d, *J* = 8.5 Hz, 2H), 7.71 (d, *J* = 8.7 Hz, 1H), 7.44 (dd, *J* = 8.6, 2.0 Hz, 1H), 7.29 (d, *J* = 6.8 Hz, 1H), 2.75 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 160.2, 148.2, 135.9, 135.2, 128.7, 127.7, 126.7, 124.8, 122.2, 25.3. Anal Calcd for $C_{10}H_8ClN$: C, 67.62; H, 4.54. Found: C, 67.70; H, 4.47.

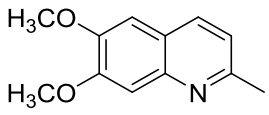


2-Methyl-7-(trifluoromethyl)quinoline (**3i**; 86 mg, 81%). Yellow solid; mp 92-94 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.36 (s, 1H), 8.12 (dd, *J* = 8.4, 3.1 Hz, 1H), 7.90 (d, *J* = 8.4 Hz, 1H), 7.67 (d, *J* = 8.5 Hz, 1H), 7.42 (dd, *J* = 8.5, 2.6 Hz, 1H), 2.80 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 160.7, 146.8, 135.9, 131.2 (q, *J* = 32.7 Hz) 128.6, 126.5 (q, *J* = 4.3 Hz), 124.0 (q, *J* = 273.4 Hz), 123.9, 121.4 (q, *J* = 3.1 Hz), 25.3. ^{19}F NMR (376 MHz, $CDCl_3$) δ -62.65. Anal Calcd for $C_{11}H_8F_3N$: C, 62.56; H, 3.82. Found: C, 62.68; H, 3.75.

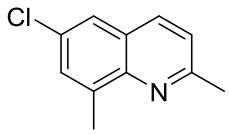


2,8-Dimethylquinoline (**3j**; 71 mg, 90 %).[5] Yellow solid; mp 26-27 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.02 (d, *J* = 8.4 Hz, 1H), 7.64 (d, *J* = 8.1 Hz, 1H), 7.56 (d, *J* = 6.9 Hz, 1H), 7.42 – 7.36 (m, 1H), 7.29 (d, *J* = 8.4 Hz, 1H), 2.85 (s, 3H), 2.80 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 157.9, 147.0, 136.5, 136.2, 129.5, 128.3, 126.4, 125.4 (d, *J* = 23.4

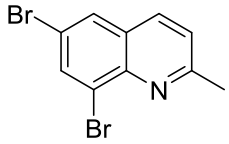
Hz), 121.6, 25.7, 18.0. Anal Calcd for $C_{11}H_{11}N$: C, 84.04; H, 7.05. Found: C, 84.16; H, 6.98.



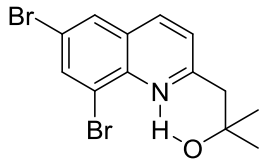
6,7-Dimethoxy-2-methylquinoline (**3k**; 54 mg, 53%).[3] Orange solid; mp 101-102 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.91 – 7.83 (m, 1H), 7.39 – 7.33 (m, 1H), 7.18 – 7.09 (m, 1H), 7.02 – 6.96 (m, 1H), 4.00 (s, 3H), 3.97 (s, 3H), 2.67 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 156.5, 152.4, 149.1, 144.7, 134.5, 121.7, 120.0, 107.5, 105.1, 56.0 (d, J = 10.2 Hz), 24.9. Anal Calcd for $C_{12}H_{13}NO_2$: C, 70.92; H, 6.45. Found: C, 71.07; H, 6.57.



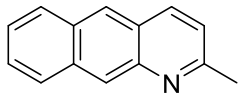
6-Chloro-2,8-dimethylquinoline (**3l**; 84 mg, 88 %). Yellow solid; mp 73-74 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.90 (d, J = 8.4 Hz, 1H), 7.58 (d, J = 2.3 Hz, 1H), 7.48 (m, 1H), 7.28 (d, J = 8.4 Hz, 1H), 2.79 (s, 3H), 2.76 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 158.1, 145.4, 138.9, 135.3, 130.7, 130.0, 127.0, 124.0, 122.5, 25.6, 17.8. Anal Calcd for $C_{11}H_{10}ClN$: C, 68.94; H, 5.26. Found: C, 69.05; H, 5.32.



6,8-Dibromo-2-methylquinoline (**3m**; 61 mg, 41 %). Yellow solid; mp 91-92 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.11 (d, *J* = 2.1 Hz, 1H), 7.93 (d, *J* = 8.4 Hz, 1H), 7.89 (d, *J* = 2.1 Hz, 1H), 7.35 (d, *J* = 8.4 Hz, 1H), 2.81 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 160.8, 143.7, 135.6 (d, *J* = 7.7 Hz), 129.4, 128.3, 125.3, 123.7, 118.6, 25.7. Anal Calcd for $C_{10}H_7Br_2N$: C, 39.91; H, 2.34. Found: C, 40.02; H, 2.45.

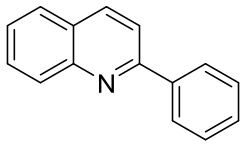


1-(6,8-Dibromoquinolin-2-yl)-2-methylpropan-2-ol (**3m′**; 101 mg, 57 %). Yellow solid; mp 103-105 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.09 (d, *J* = 2.0 Hz, 1H), 8.00 (d, *J* = 8.4 Hz, 1H), 7.89 (d, *J* = 2.0 Hz, 1H), 7.30 (d, *J* = 8.4 Hz, 1H), 6.45 (s, 1H), 3.12 (s, 2H), 1.31 (s, 6H).^{13}C NMR (101 MHz, $CDCl_3$) δ 162.3, 142.6, 136.2, 135.8, 129.4, 128.3, 125.3, 124.4, 119.3, 70.7, 48.5, 29.6. IR (ν_{max}, cm^{-1}): 3392, 2970, 2927, 1590, 1479, 1442, 1187, 975, 867, 781. Anal Calcd for $C_{13}H_{13}Br_2NO$: C, 43.49; H, 3.65. Found: C, 43.38; H, 3.79.

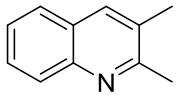


2-Methylbenzo[g]quinoline (**3n**; 62 mg, 64%). Orange solid; mp 113-114 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.62 (s, 1H), 8.34 (s, 1H), 8.20 (d, *J* = 8.7 Hz, 1H), 8.08 (d, *J* = 7.3 Hz, 1H), 8.02 (d, *J* = 7.2 Hz, 1H), 7.56 – 7.47 (m, 2H), 7.26 (d, *J* = 8.7 Hz, 1H), 2.81 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 160.0, 144.3, 136.4, 134.0, 131.3, 128.5,

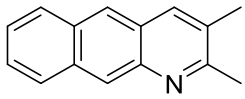
128.1, 126.4, 126.2 (d, J = 6.5 Hz), 125.7, 125.1, 121.9, 25.9. Anal Calcd for $C_{14}H_{11}N$: C, 87.01; H, 5.74. Found: C, 87.22; H, 5.65.



2-Phenylquinoline (**3o**; 85mg, 83%).[8] White solid; mp 65-67 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.26 – 8.20 (m, 4H), 7.91 (d, J = 8.6 Hz, 1H), 7.86 (d, J = 7.9 Hz, 1H), 7.76 (t, J = 7.7 Hz, 1H), 7.53 (m, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 157.4, 148.3, 139.7, 136.8, 130.1, 129.7 (d, J = 3.8 Hz), 129.4, 128.9, 128.3, 127.6, 127.5, 127.2, 126.3. Anal Calcd for $C_{15}H_{11}N$: C, 87.77; H, 5.40; Found: C, 87.68; H, 5.49.

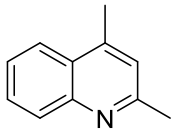


2,3-Dimethylquinoline (**3p**; 57 mg, 73%).[3] Light yellow solid; mp 68-70 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.02 (d, J = 8.4 Hz, 1H), 7.85 (s, 1H), 7.72 (d, J = 8.1 Hz, 1H), 7.67 – 7.60 (m, 1H), 7.47 (t, J = 7.5 Hz, 1H), 2.71 (s, 3H), 2.46 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 159.0, 146.5, 135.2, 130.0, 128.3 (d, J = 7.0 Hz), 127.5, 126.7, 125.6, 23.6, 19.6. Anal Calcd for $C_{11}H_{11}N$: C, 84.04; H, 7.05. Found: C, 84.15; H, 6.91.

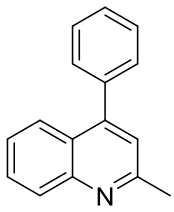


2,3-Dimethylbenzo[g]quinoline (**3q**; 70 mg, 68%). Orange solid; mp 139-140 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.61 (s, 1H), 8.27 (s, 1H), 8.12 – 7.94 (m, 3H), 7.55 – 7.44

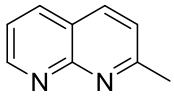
(m, 2H), 2.77 (s, 3H), 2.50 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 160.5, 143.3, 134.9, 133.4, 131.5, 129.9, 128.5, 127.9, 126.3, 125.9, 125.7, 125.6, 125.2, 24.0, 19.8. Anal Calcd for $C_{15}H_{13}N$: C, 86.92; H, 6.32. Found: C, 86.08; H, 6.45. ESI-MS m/z: $[M+H]^+$ Calcd for $C_{15}H_{14}N$: 208.1, found 208.1.



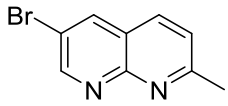
2,4-Dimethylquinoline (**3r**; 49 mg, 62%).[3] Light yellow liquid; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.03 (d, *J* = 8.4 Hz, 1H), 7.91 (t, *J* = 6.2 Hz, 1H), 7.71 – 7.62 (m, 1H), 7.48 (dd, *J* = 11.8, 6.2 Hz, 1H), 7.10 (d, *J* = 5.4 Hz, 1H), 2.69 (s, 3H), 2.64 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 158.6, 147.7, 144.1, 129.1, 126.5, 125.4, 123.5, 122.7, 25.2, 18.5. Anal Calcd for $C_{11}H_{11}N$: C, 84.04; H, 7.05. Found: C, 84.18; H, 6.87.



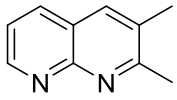
2-Methyl-4-phenylquinoline (**3s**; 67 mg, 61%).[3] Light yellow solid; mp 93-95 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.12 (d, *J* = 8.4 Hz, 1H), 7.88 (d, *J* = 8.4 Hz, 1H), 7.74 – 7.66 (m, 1H), 7.57 – 7.39 (m, 6H), 7.24 (s, 1H), 2.80 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 158.5, 148.5, 148.4 (d, *J* = 2.0 Hz), 138.2, 138.1, 129.5, 129.3, 129.0 (d, *J* = 2.6 Hz), 128.5, 128.3, 125.7 (d, *J* = 9.5 Hz), 125.1, 122.2, 25.4. Anal Calcd for $C_{16}H_{13}N$: C, 87.64; H, 5.98. Found: C, 87.55; H, 6.09.



2-Methyl-1,8-naphthyridine (**4a**; 59mg, 82%).[9] Red solid; mp 98-99 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.08 (s, 1H), 8.17 – 8.13 (m, 1H), 8.09 (dd, *J* = 8.3, 2.7 Hz, 1H), 7.48 – 7.42 (m, 1H), 7.39 (dd, *J* = 8.3, 2.8 Hz, 1H), 2.82 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 163.1, 155.7, 153.2, 136.9 (d, *J* = 17.6 Hz), 123.1, 121.40, 120.8, 25.6 . Anal Calcd for $C_9H_8N_2$: C, 74.98; H, 5.59. Found: C, 74.85; H, 5.78; IR υ (cm^{-1}) 3421, 2920, 1612, 1500, 1299, 808, 781.

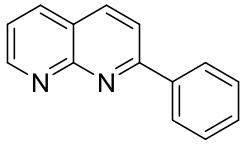


6-Bromo-2-methyl-1,8-naphthyridine (**4b**; 80mg, 72%). Light yellow solid; mp 184-185 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.02 (d, *J* = 2.3 Hz, 1H), 8.25 (d, *J* = 2.3 Hz, 1H), 7.97 (d, *J* = 8.3 Hz, 1H), 7.37 (d, *J* = 8.3 Hz, 1H), 2.77 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 163.5, 154.3, 154.1, 137.8, 135.9, 123.9, 121.7, 117.1, 25.7. Anal Calcd for $C_9H_7BrN_2$: C, 48.46; H, 3.16; Found: C, 48.52; H, 3.02.

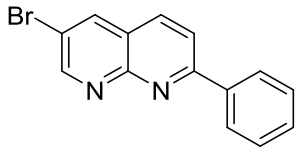


2,3-Dimethyl-1,8-naphthyridine (**4c**; 56 mg, 71%). White solid; mp 132-134 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.99 (s, 1H), 7.94 (d, *J* = 90.7 Hz, 2H), 7.37 (s, 1H), 2.74 (s, 3H), 2.46 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 162.9 (d, *J* = 3.0 Hz), 154.8 (d, *J* = 3.0

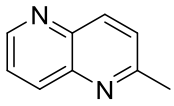
Hz), 152.2 (d, J = 3.0 Hz), 135.8 (d, J = 17.0 Hz), 131.4, 121.6, 121.3, 23.9, 19.3. Anal Calcd for $C_{10}H_{10}N_2$: C, 75.92; H, 6.37. Found: C, 76.03; H, 6.23.



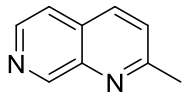
2-Phenyl-1,8-naphthyridine (**4d**; 62mg, 60%).[10] Light yellow solid; mp 109-110 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.15 (s, 1H), 8.34 (d, J = 7.6 Hz, 2H), 8.26 (d, J = 8.4 Hz, 1H), 8.20 (d, J = 8.0 Hz, 1H), 8.02 (dd, J = 8.5, 1.9 Hz, 1H), 7.59 – 7.43 (m, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 160.3, 156.1, 153.8, 138.5, 137.7, 136.7, 130.1, 128.8, 127.9, 121.7, 119.7. Anal Calcd for $C_{14}H_{10}N_2$: C, 81.53; H, 4.89; Found: C, 81.68; H, 4.78.



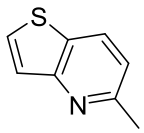
6-Bromo-2-phenyl-1,8-naphthyridine (**4e**; 132mg, 93%). Light yellow solid; mp 190-191 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.14 (s, 1H), 8.60 – 7.94 (m, 5H), 7.54 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 160.5, 154.8, 154.3, 137.9 (d, J = 17.0 Hz), 136.8, 130.4, 128.9, 127.9, 120.5. Anal Calcd for $C_{14}H_9BrN_2$: C, 58.97; H, 3.18; Found: C, 59.05; H, 3.29. ESI-MS m/z: $[M+H]^+$ Calcd for $C_{14}H_{10}BrN_2$: 285.0, found 285.0.



2-Methyl-1,5-naphthyridine (**4f**; 66mg, 92%).[11] Light yellow solid; mp 55-56 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.94 (s, 1H), 8.31 (dd, *J* = 11.8, 8.9 Hz, 2H), 7.62 (dd, *J* = 7.6, 3.3 Hz, 1H), 7.53 (d, *J* = 8.5 Hz, 1H), 2.79 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 160.1, 150.1, 142.7, 137.4, 136.5, 125.4, 124.3, 25.3. Anal Calcd for $C_9H_8N_2$: C, 74.98; H, 5.59; Found: C, 75.12; H, 5.45.



2-Methyl-1,7-naphthyridine (**4g**; 69mg, 96%).[12] White solid; mp 40-41 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.41 (s, 1H), 8.55 (d, *J* = 5.5 Hz, 1H), 8.02 (d, *J* = 8.5 Hz, 1H), 7.59 (d, *J* = 5.5 Hz, 1H), 7.47 (d, *J* = 8.5 Hz, 1H), 2.77 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 161.0, 153.2, 143.0, 134.7, 129.5, 126.2, 25.5. Anal Calcd for $C_9H_8N_2$: C, 74.98; H, 5.59; Found: C, 75.07; H, 5.48.



5-Methylthieno[3,2-b]pyridine (**4h**; 47 mg, 63%). Light yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.08 (d, *J* = 8.3 Hz, 1H), 7.71 (d, *J* = 5.5 Hz, 1H), 7.51 (d, *J* = 6.2 Hz, 1H), 7.14 (d, *J* = 8.3 Hz, 1H), 2.70 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 156.0, 155.7, 130.5 (d, *J* = 16.1 Hz), 130.3, 124.8, 119.1, 24.5. Anal Calcd for C_8H_7NS: C, 64.40; H, 4.73. Found: C, 64.32; H, 4.88. ESI-MS m/z: $[M+H]^+$ Calcd for C_8H_8NS: 150.0, found 150.0.

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4. NMR spectra for all the products

Figure S1. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3a**

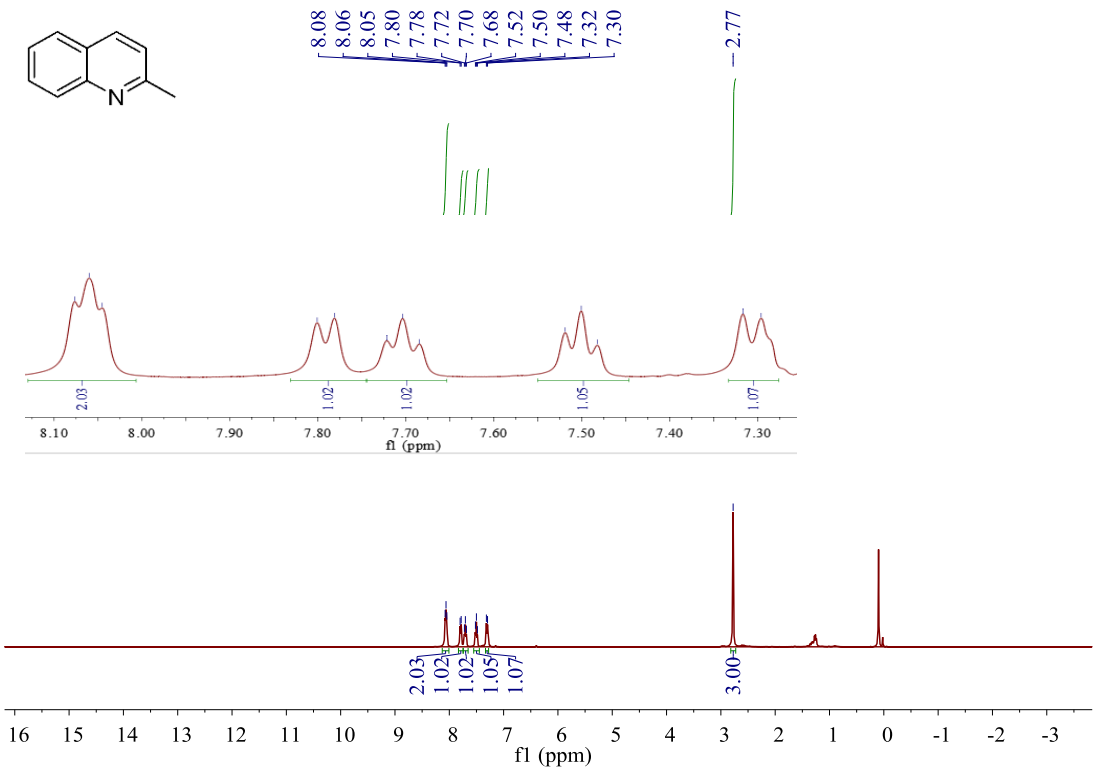

Figure S2. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **3a**

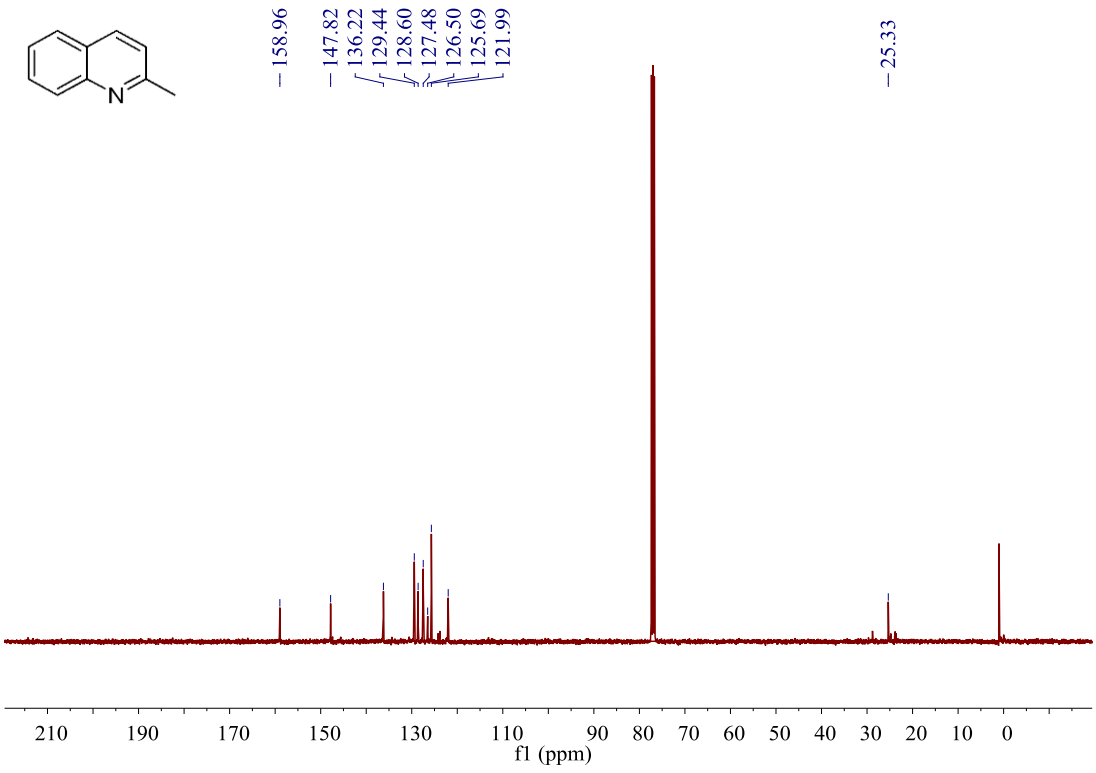

Figure S3. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3b**

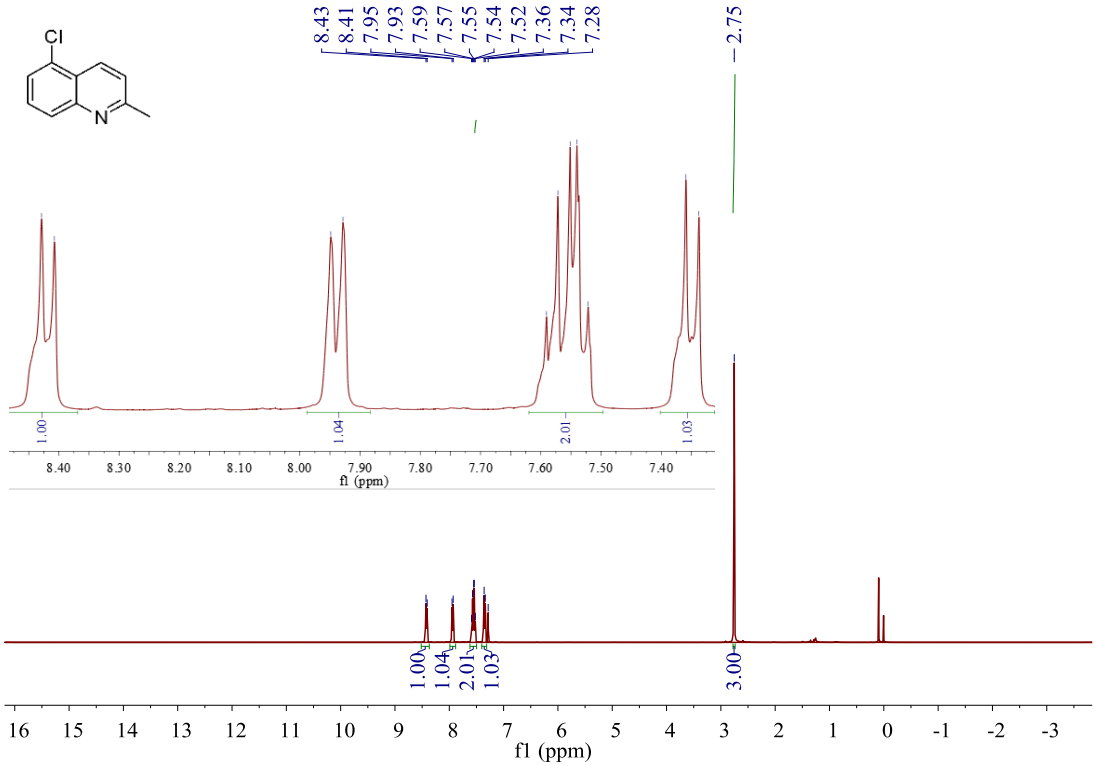

Figure S4. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **3b**

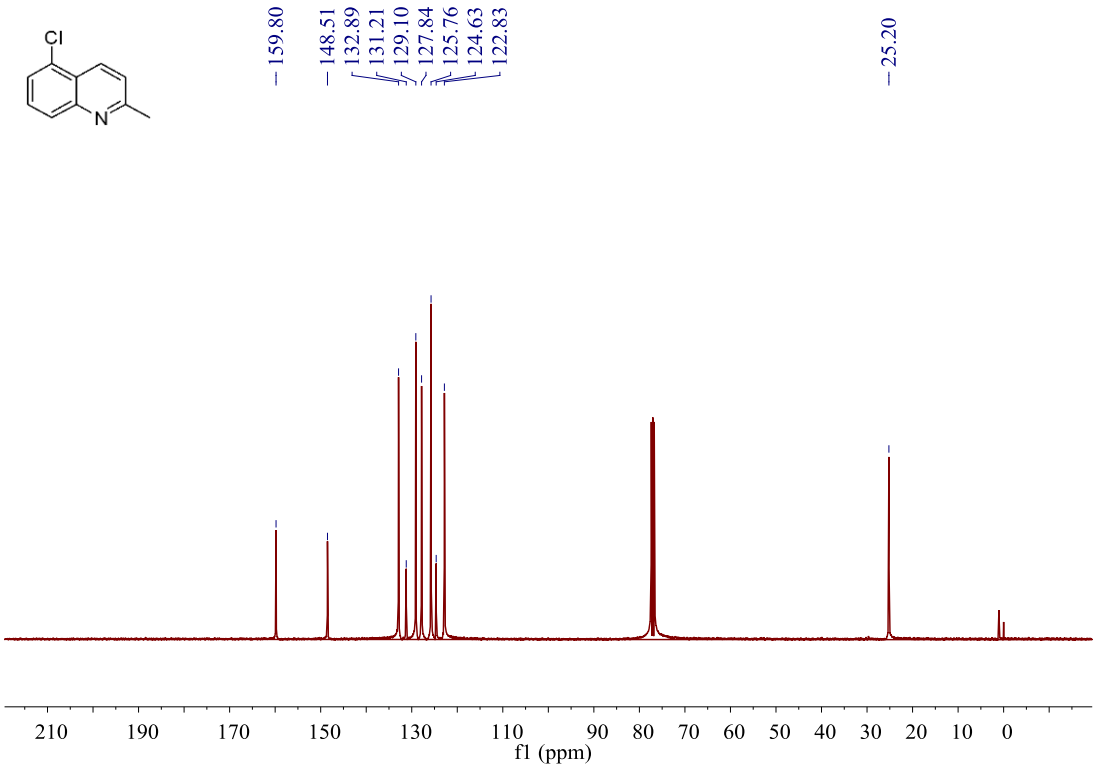

Figure S5. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3c**

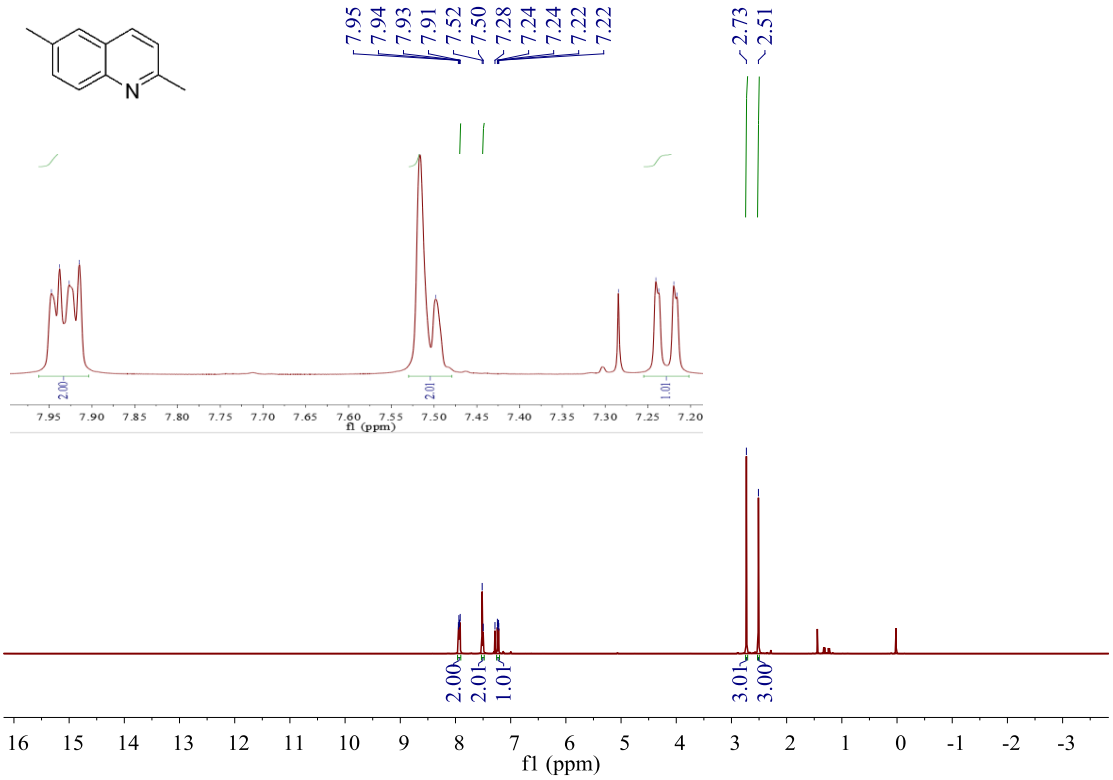

Figure S6. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **3c**

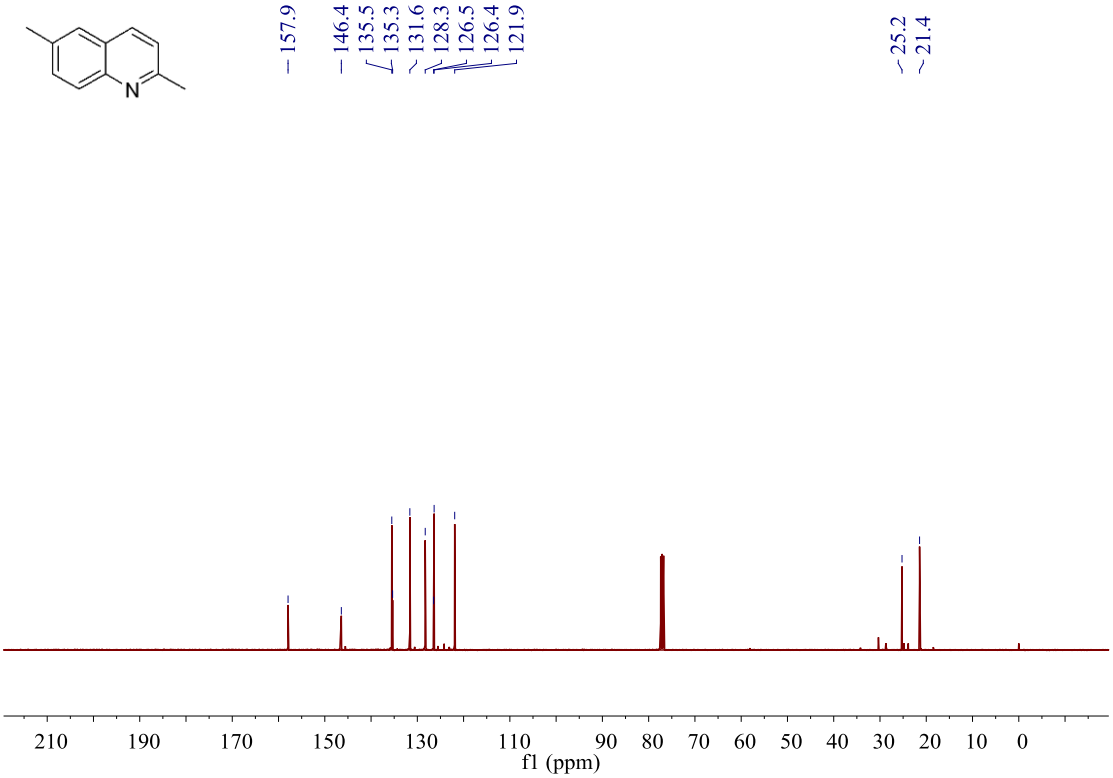

Figure S7. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3d**

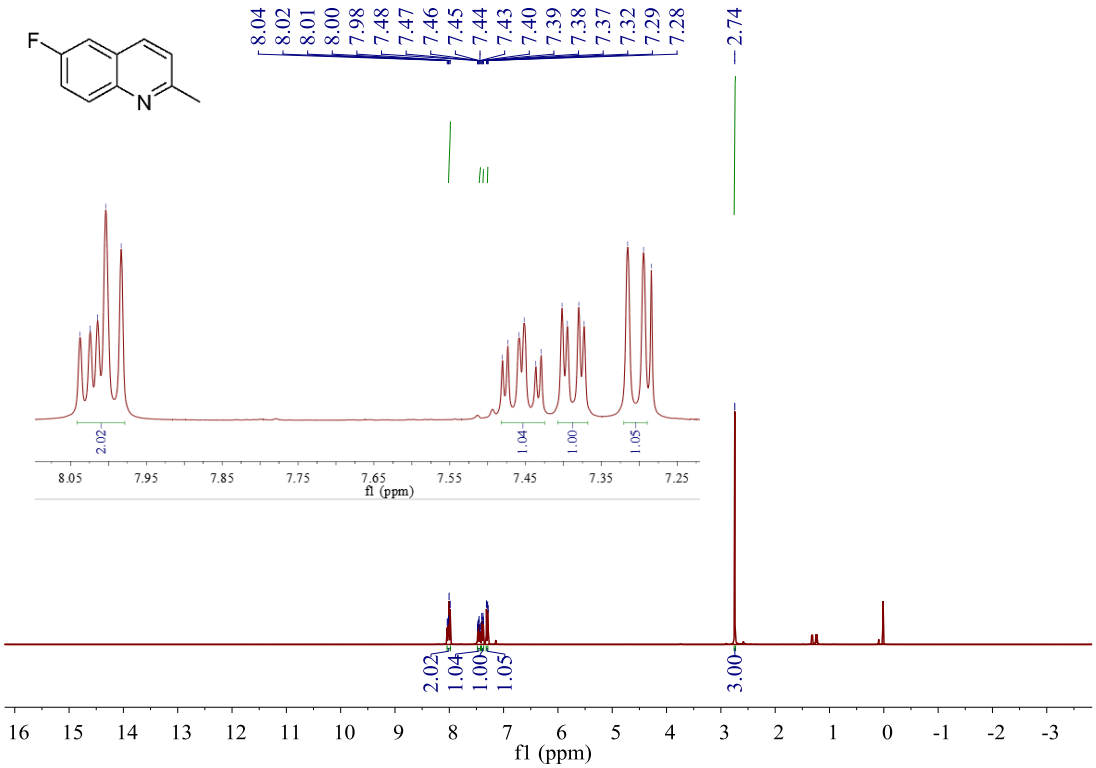

Figure S8. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **3d**

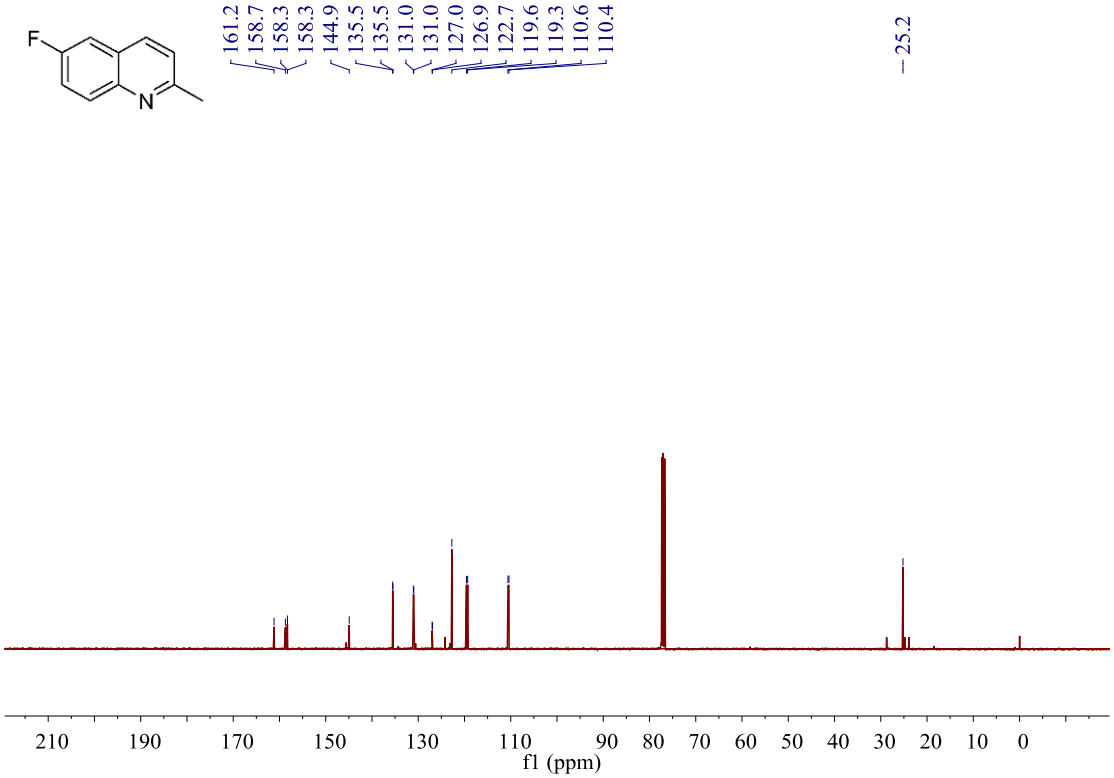

Figure S9. ^{19}F NMR (376 MHz, $CDCl_3$) spectrum of **3d**

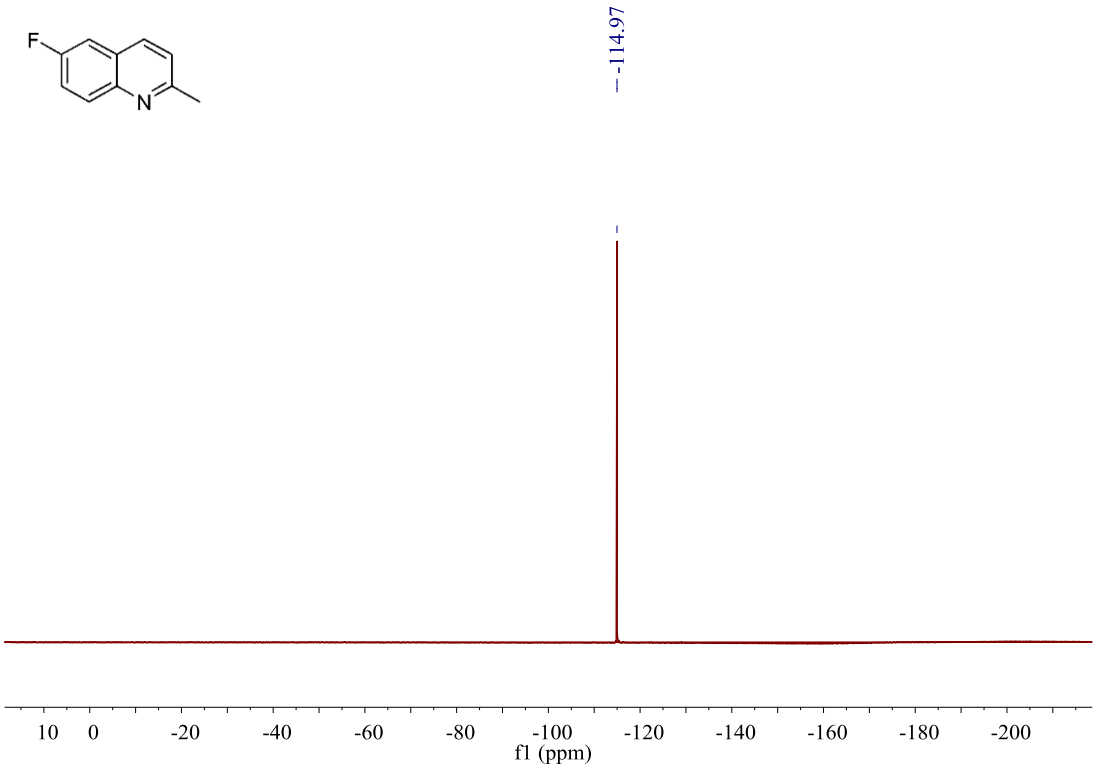

Figure S10. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3e**

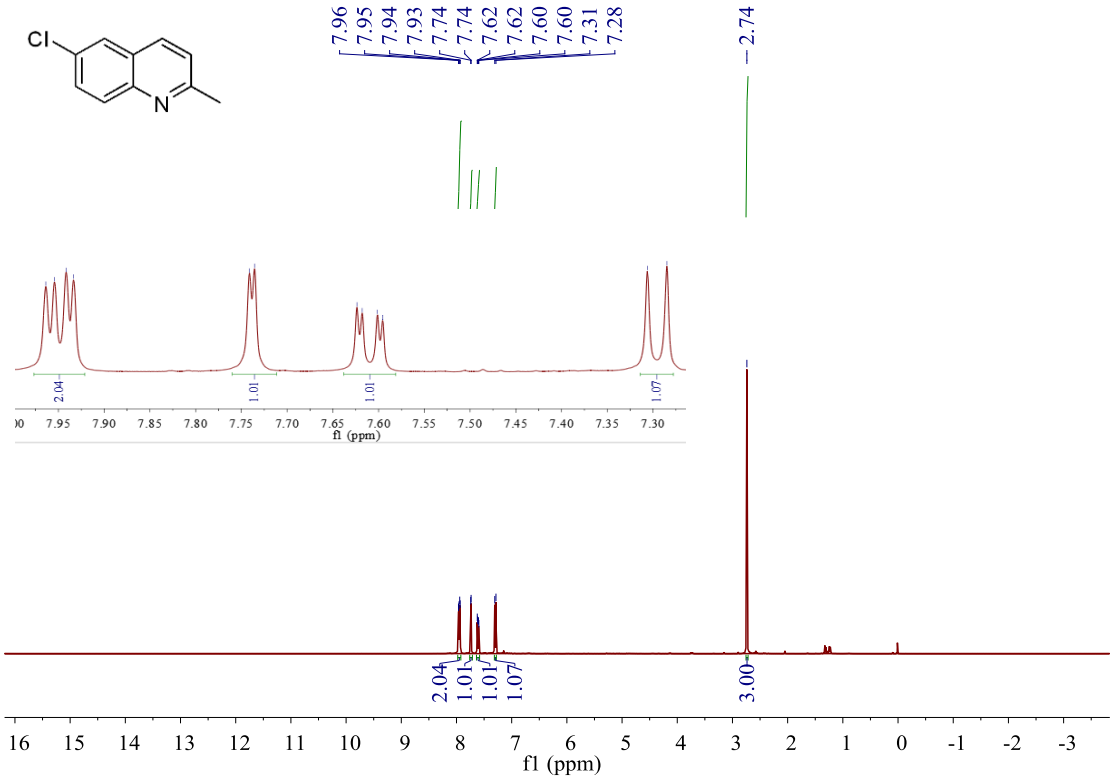

Figure S11. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **3e**

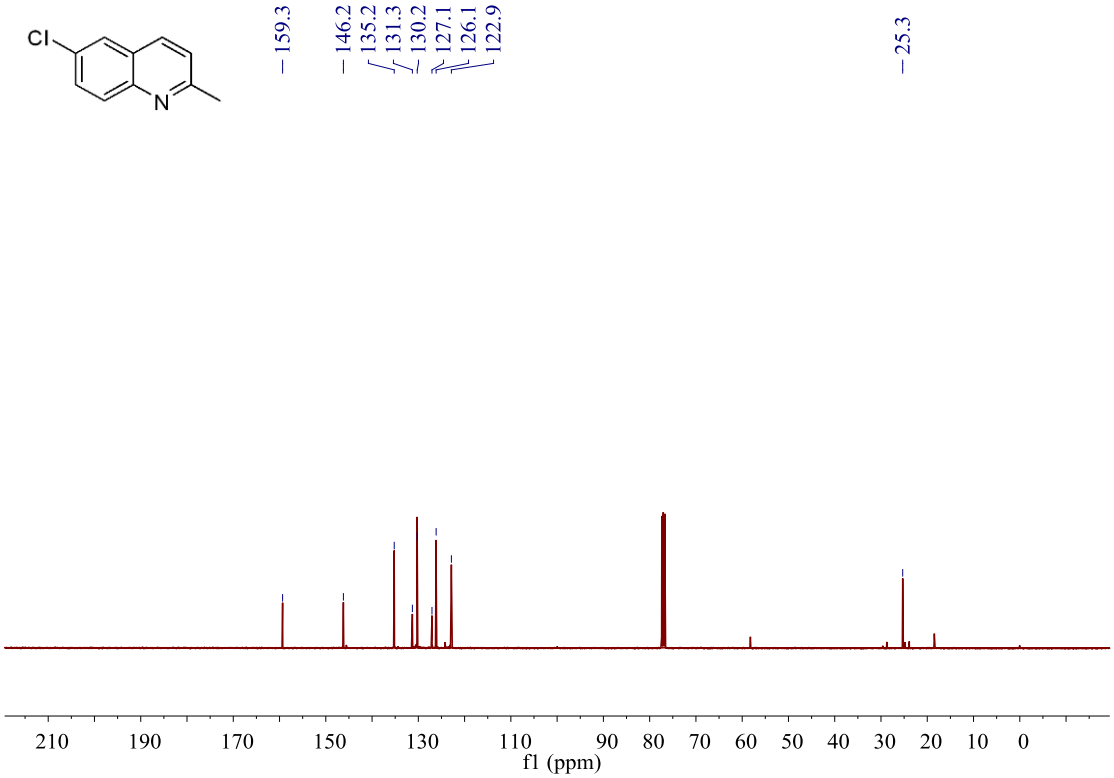

Figure S12. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3f**

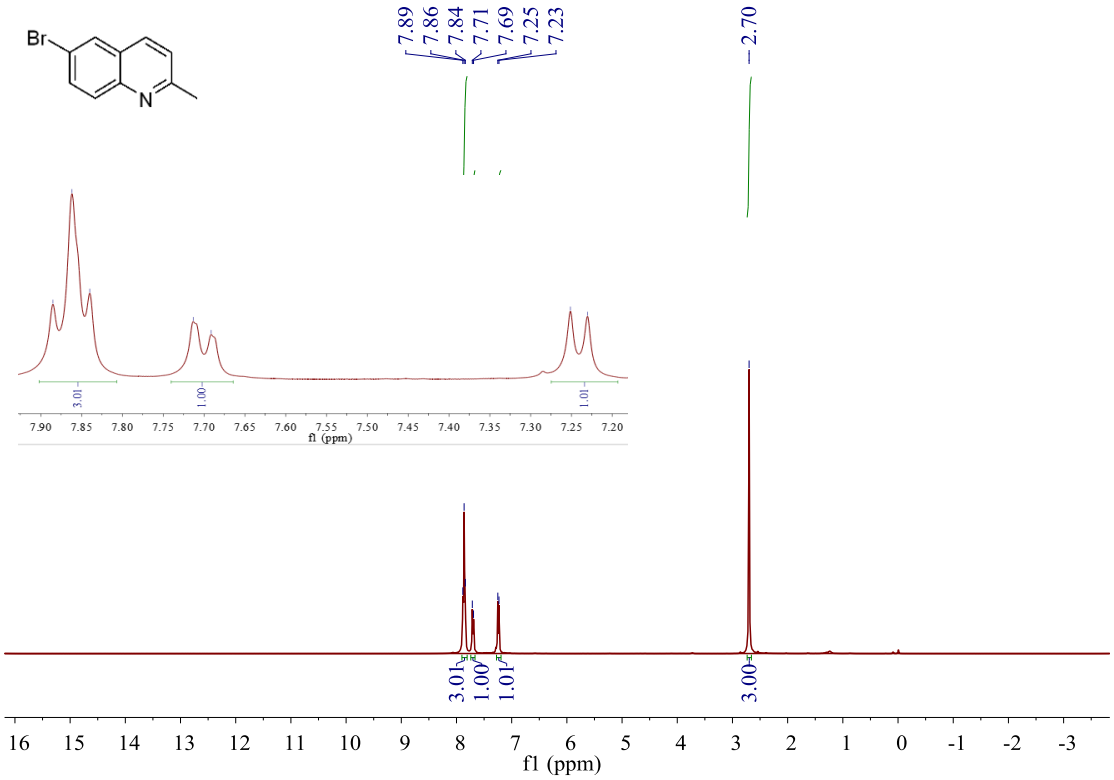

Figure S13. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **3f**

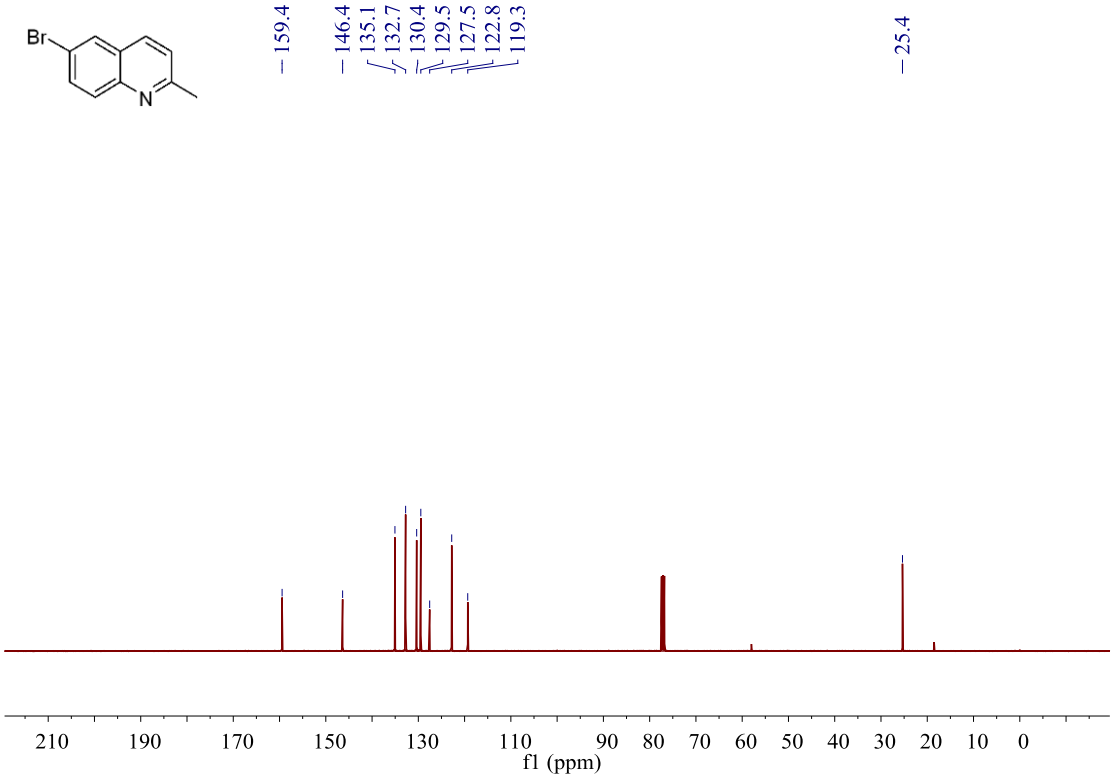

Figure S14. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3g**

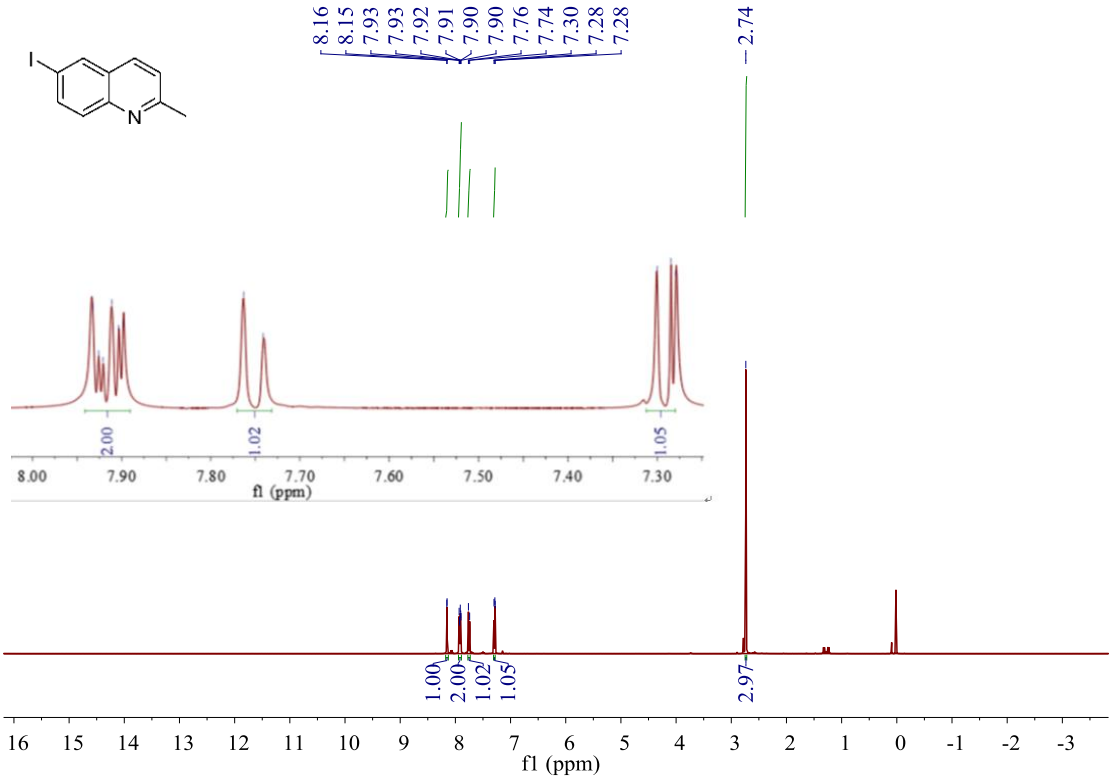

Figure S15. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **3g**

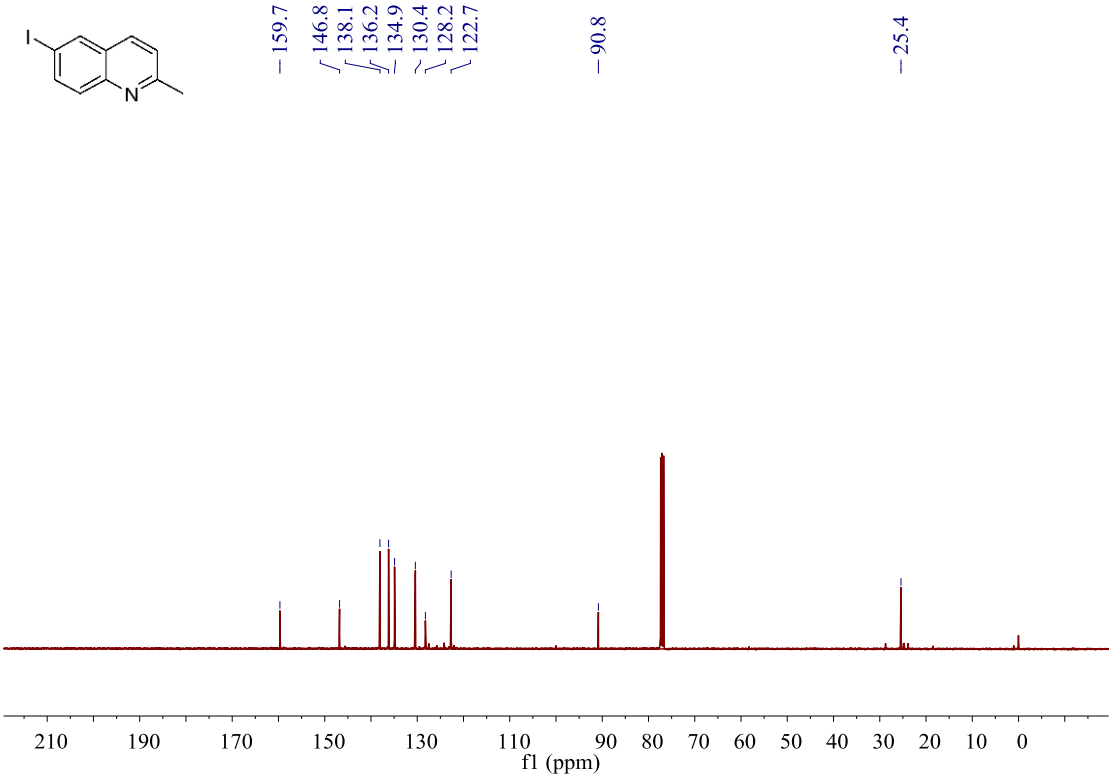

Figure S16. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3h**

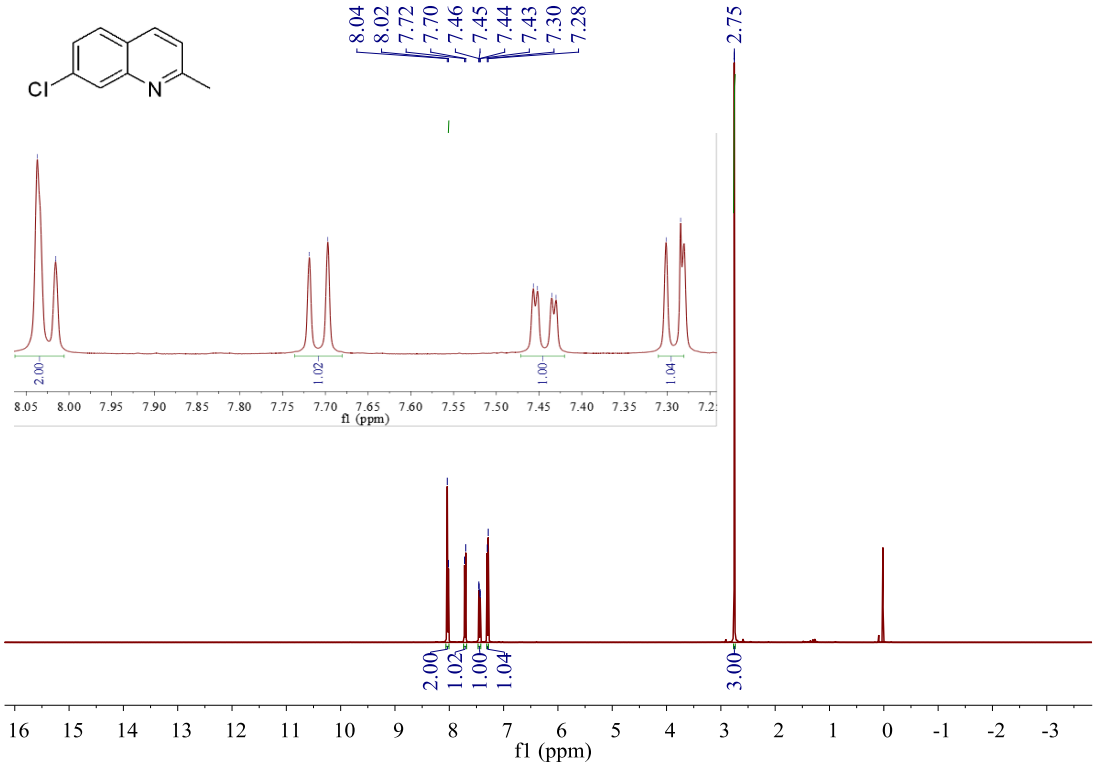

Figure S17. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **3h**

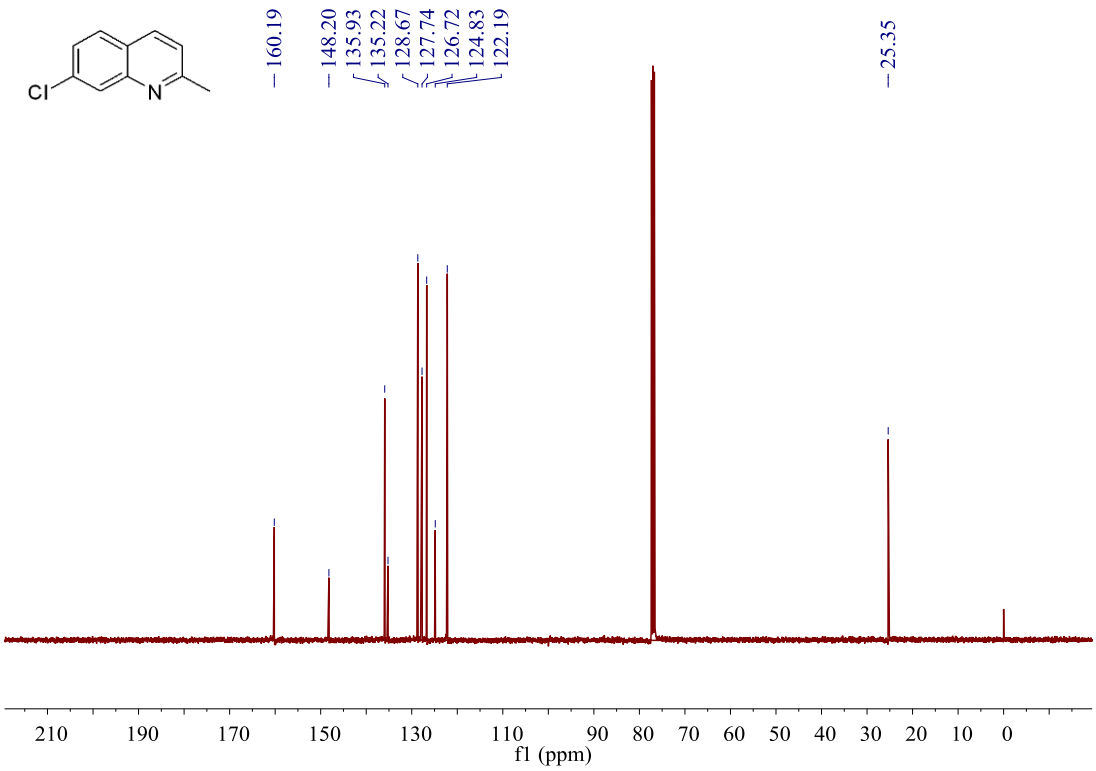

Figure S18. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3i**

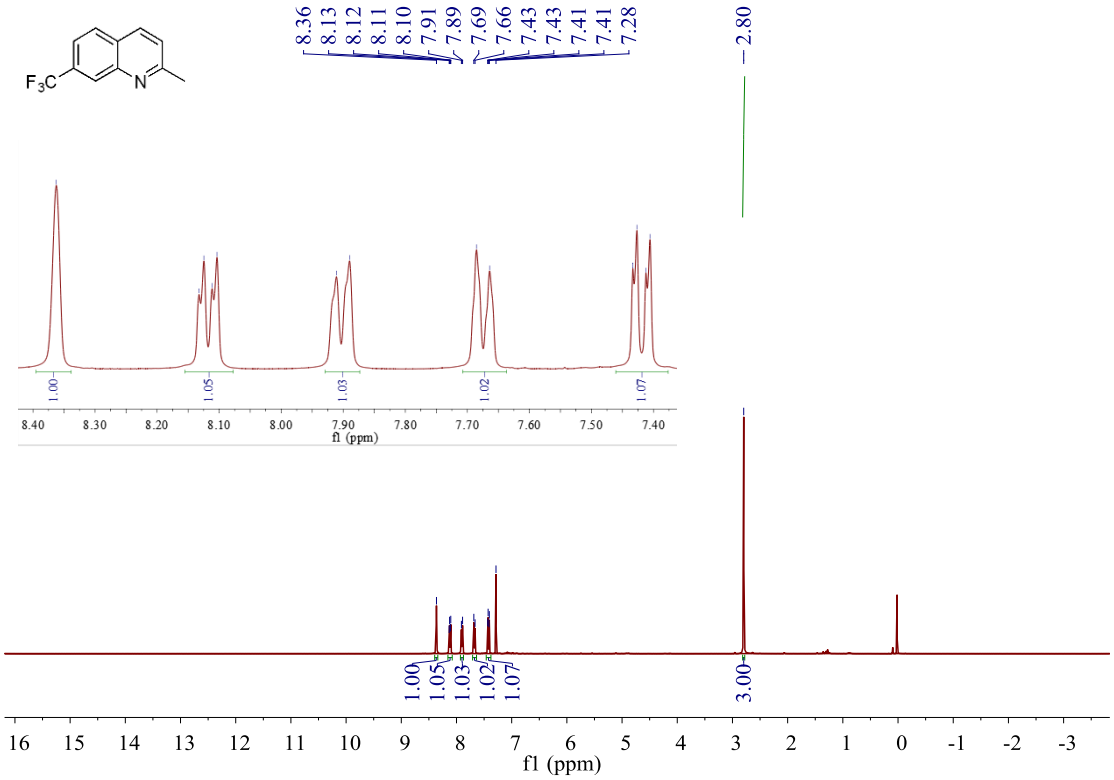

Figure S19. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **3i**

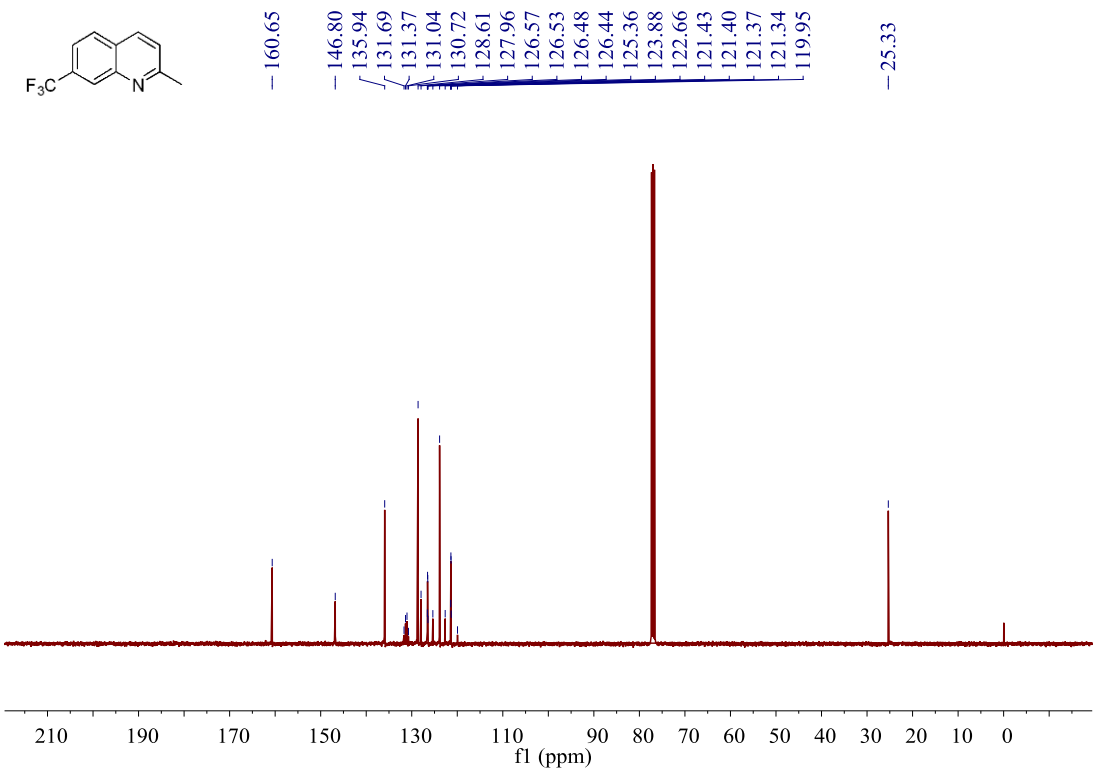

Figure S20. ^{19}F NMR (376 MHz, $CDCl_3$) spectrum of **3i**

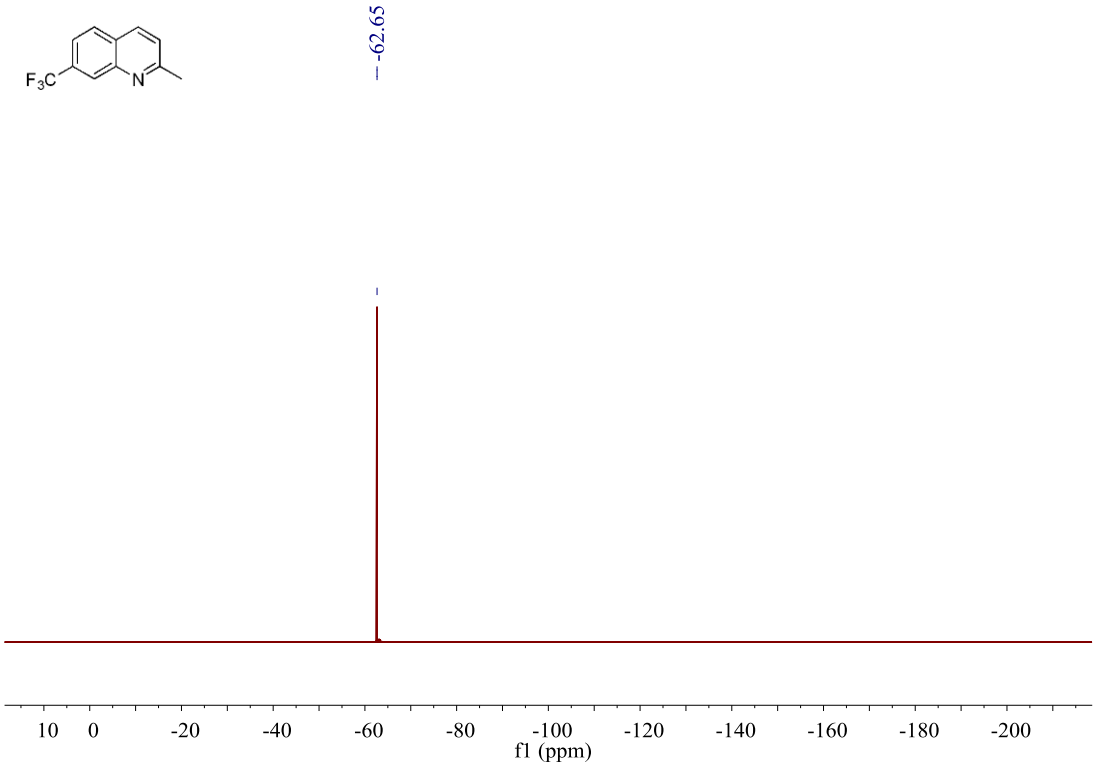

Figure S21. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3j**

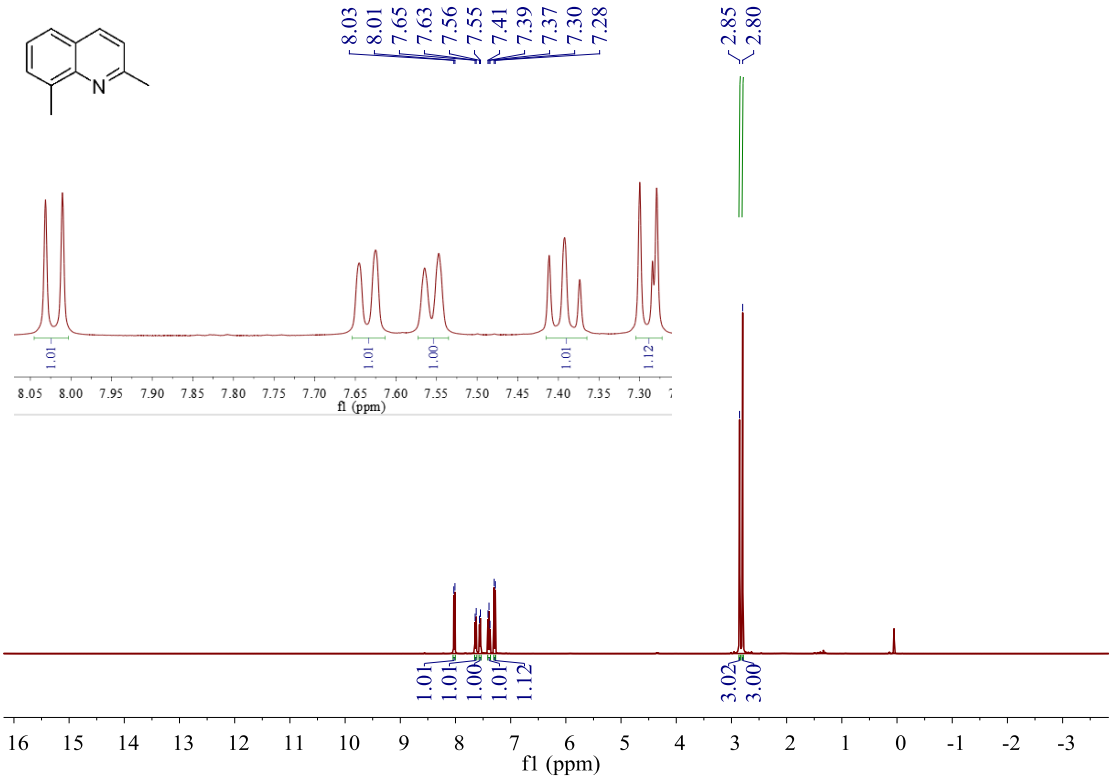

Figure S22. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **3j**

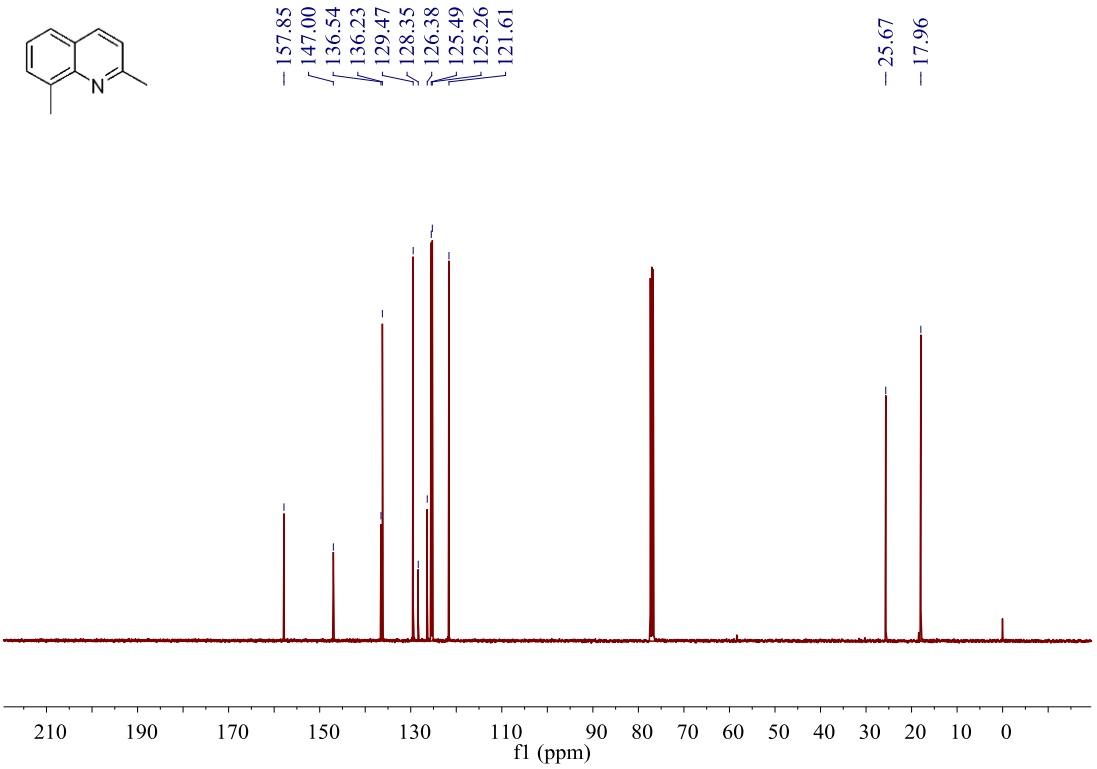

Figure S23. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3k**

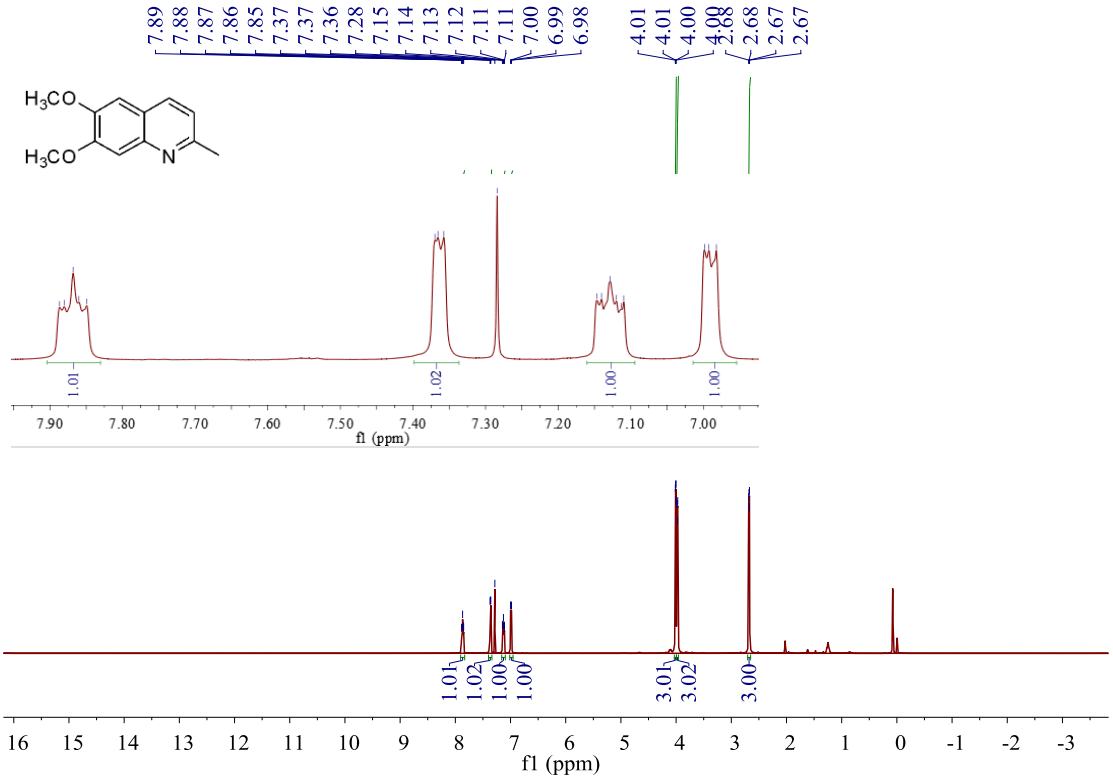

Figure S24. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **3k**

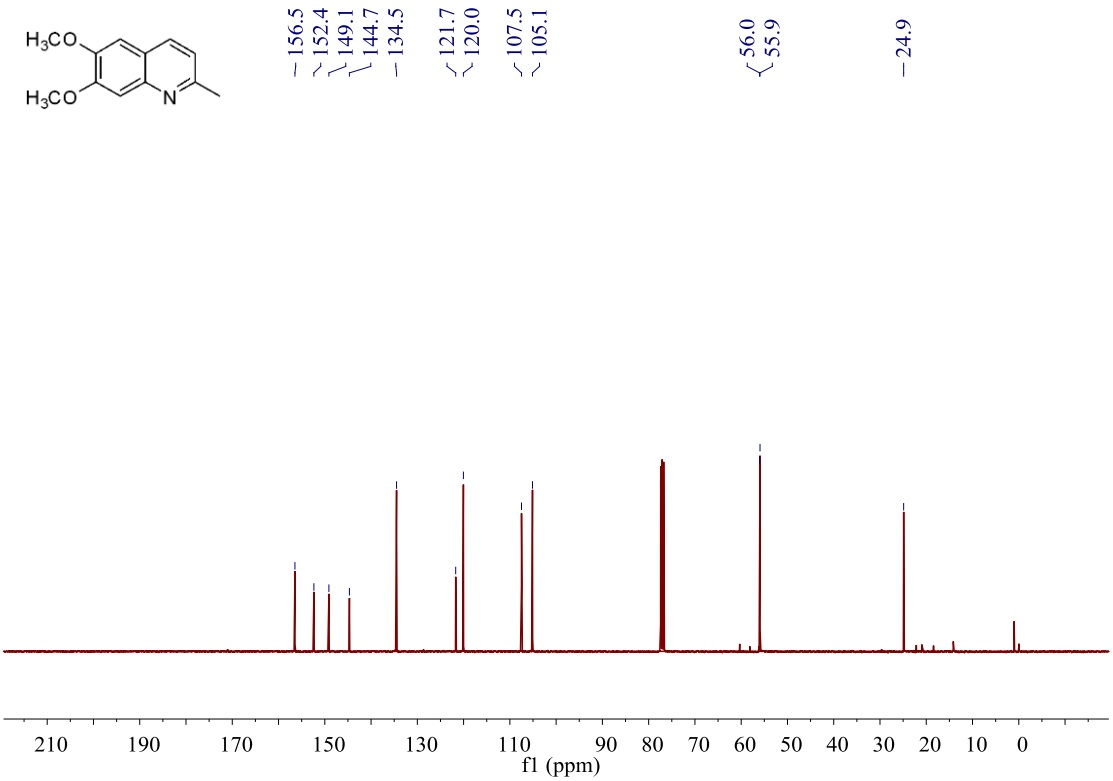

Figure S25. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3l**

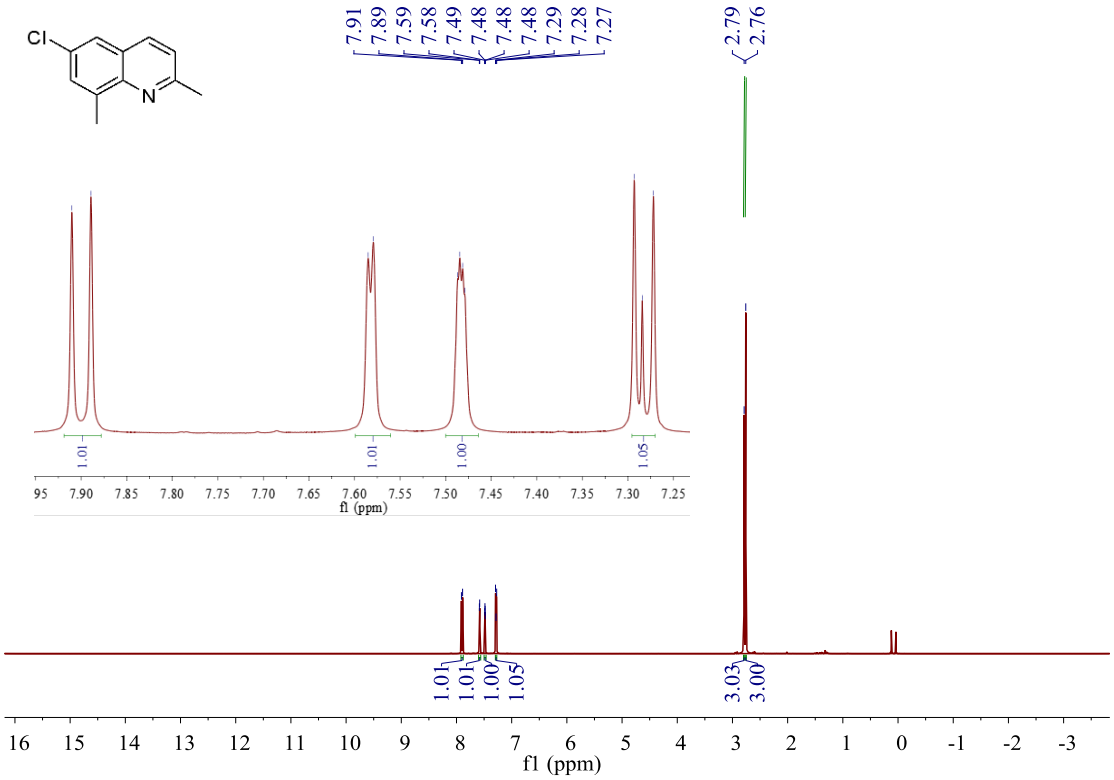

Figure S26. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **3l**

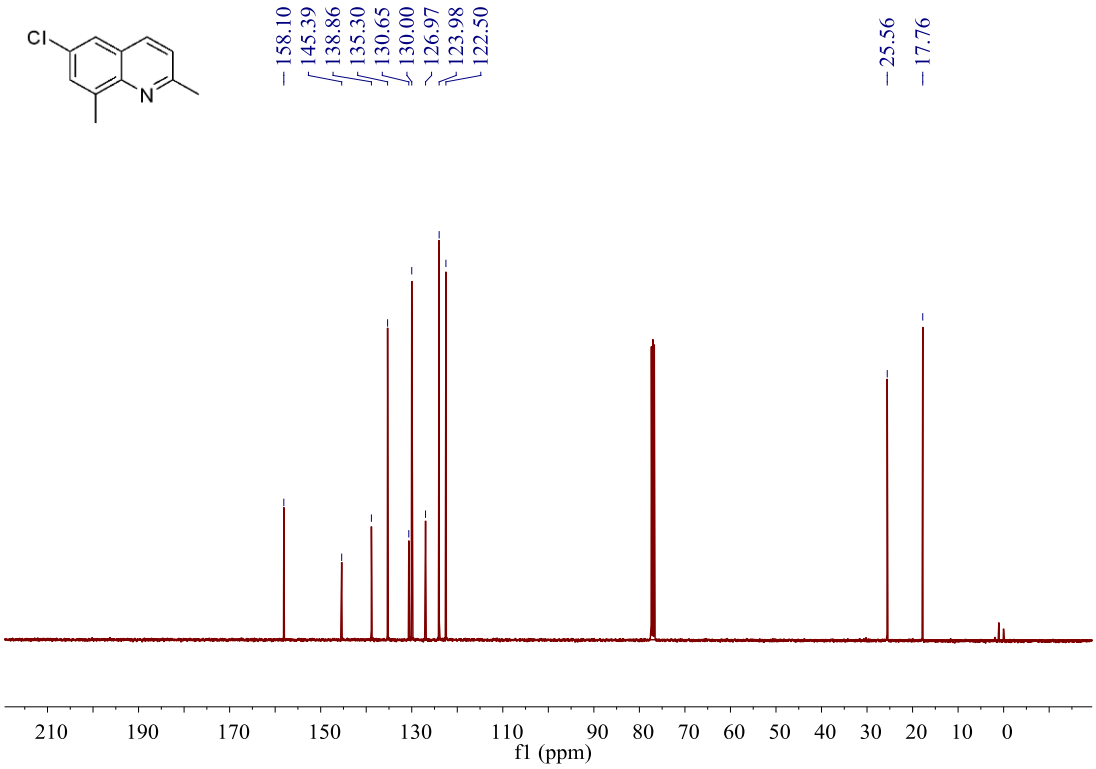

Figure S27. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3m**

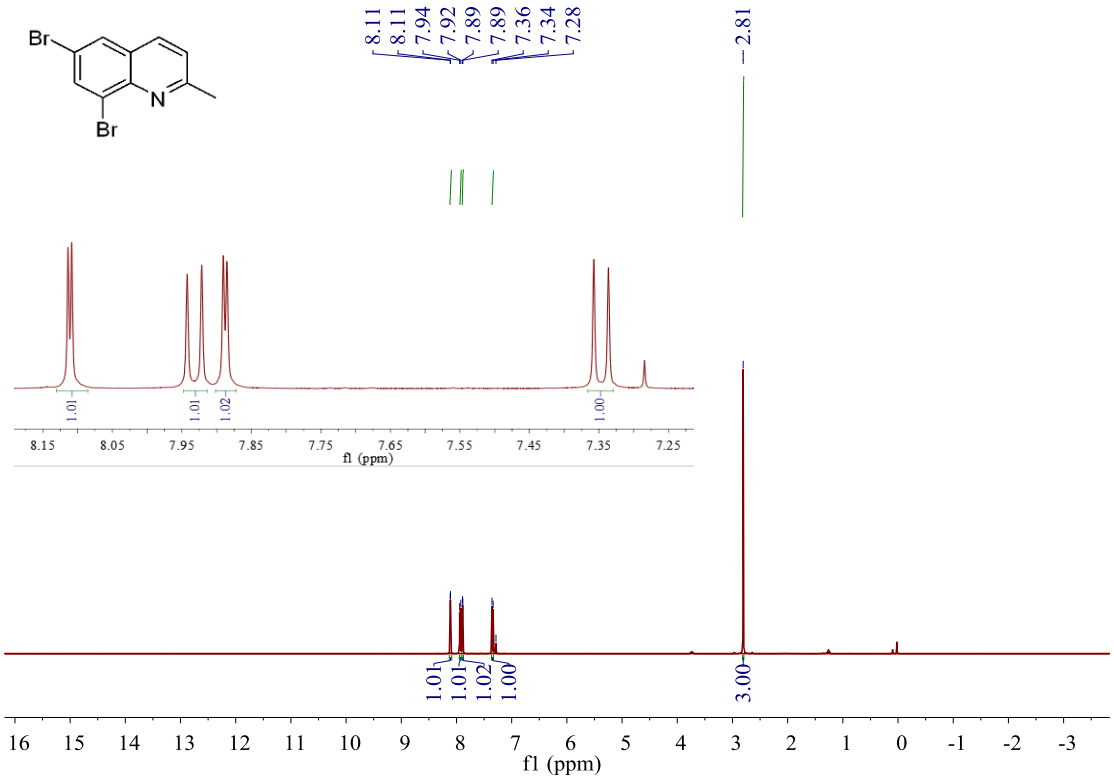

Figure S28. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **3m**

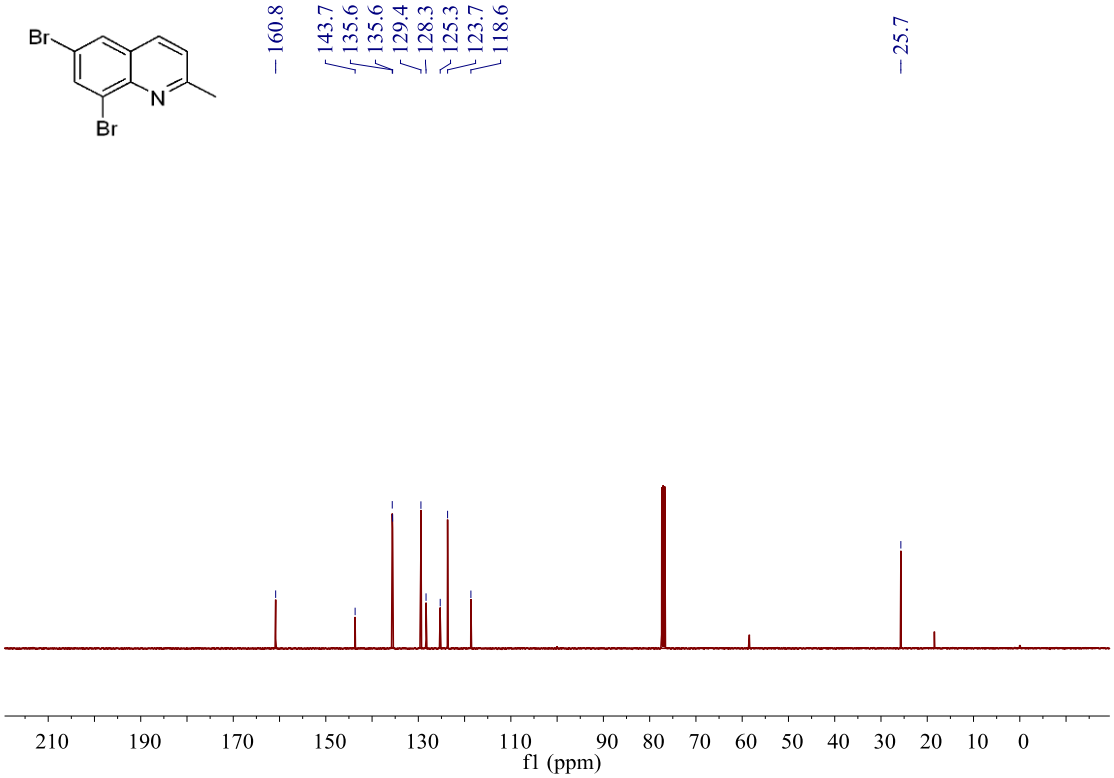

Figure S29. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3m'**

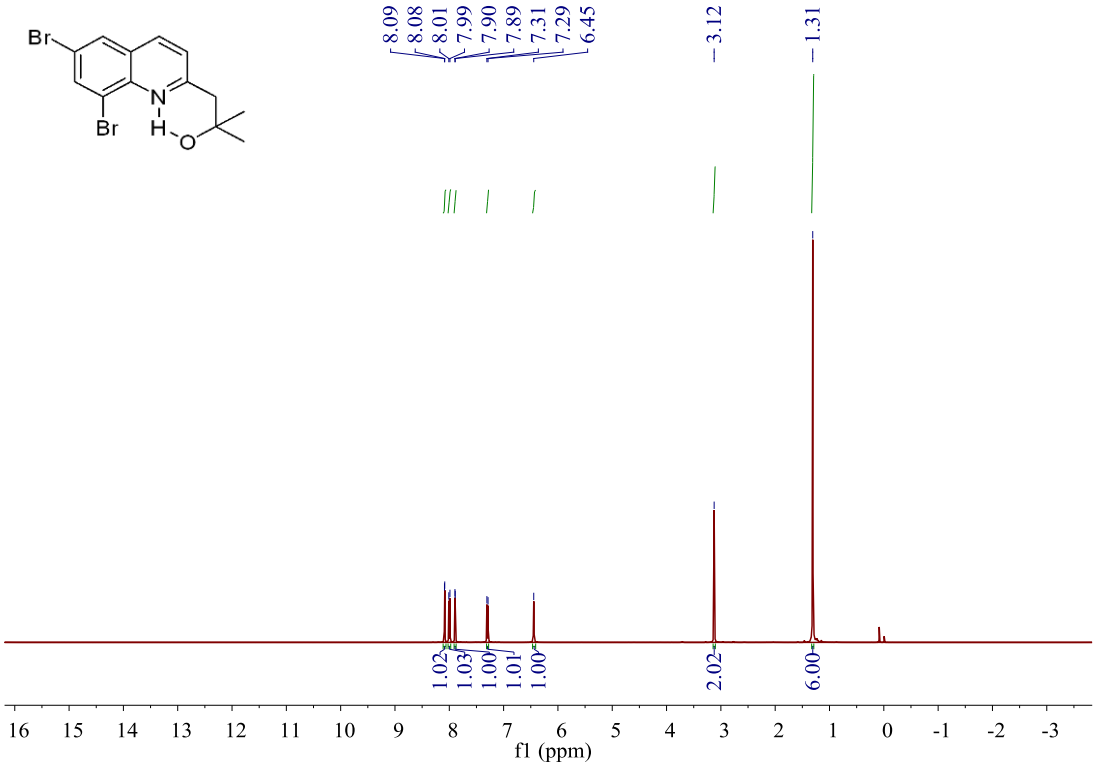

Figure S30. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **3m'**

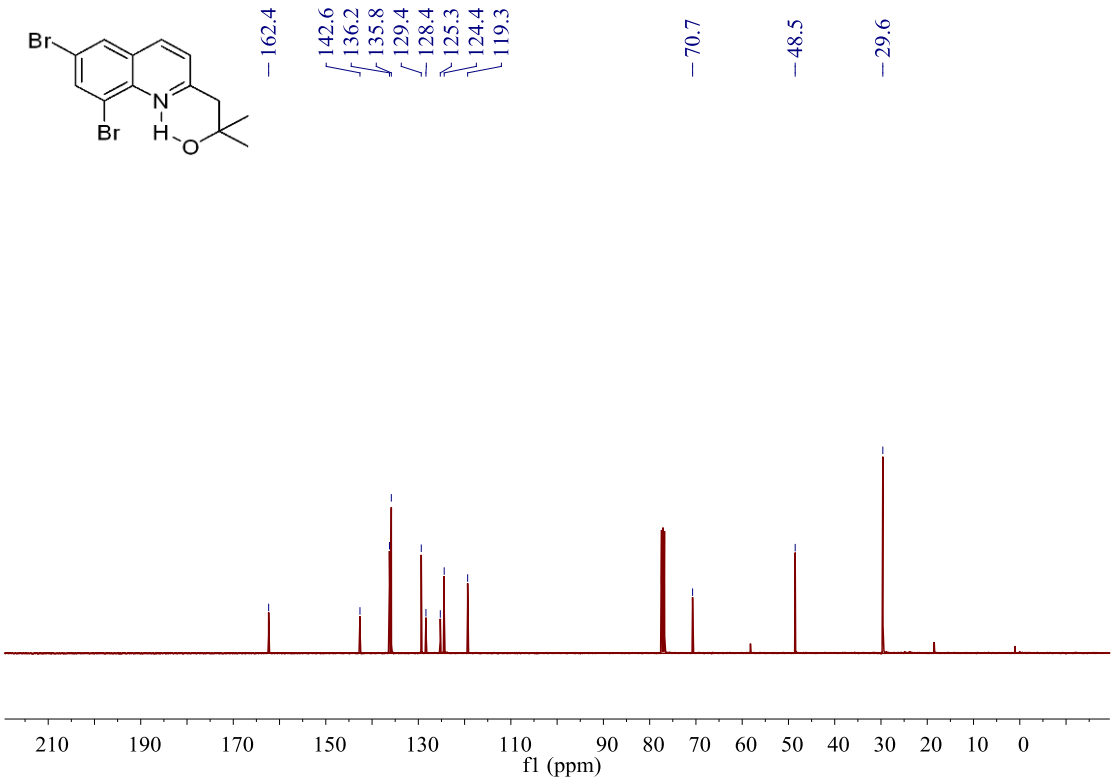

Figure S31. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3n**

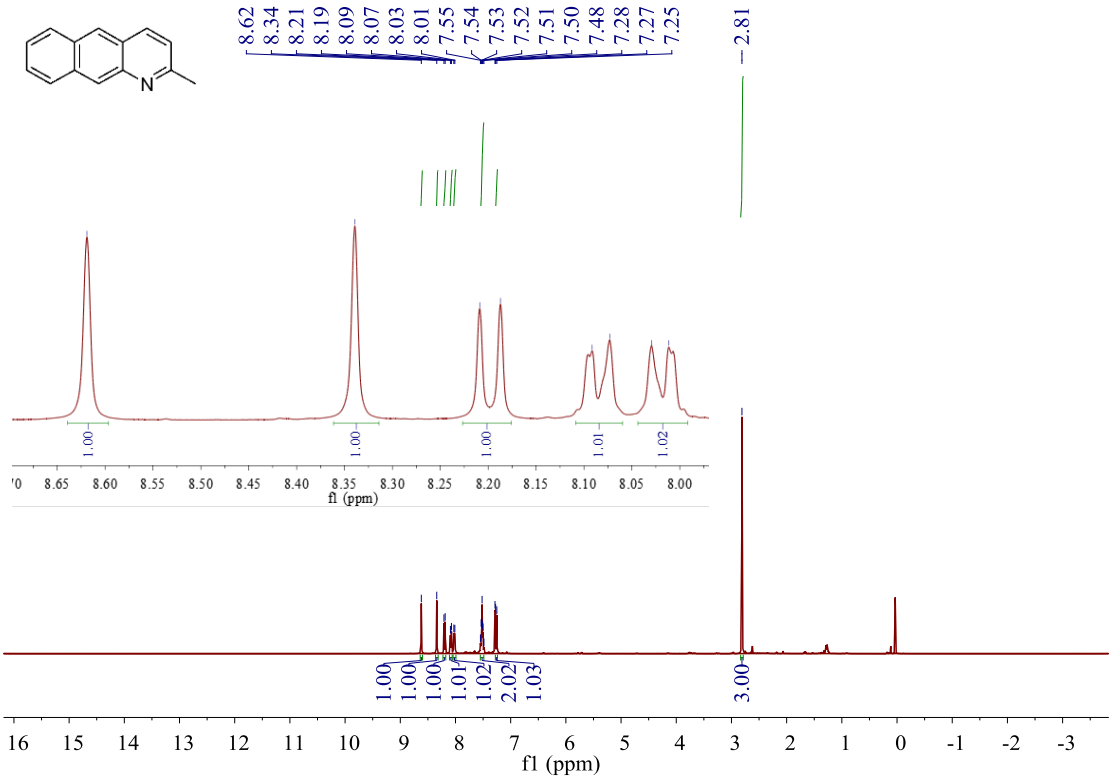

Figure S32. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **3n**

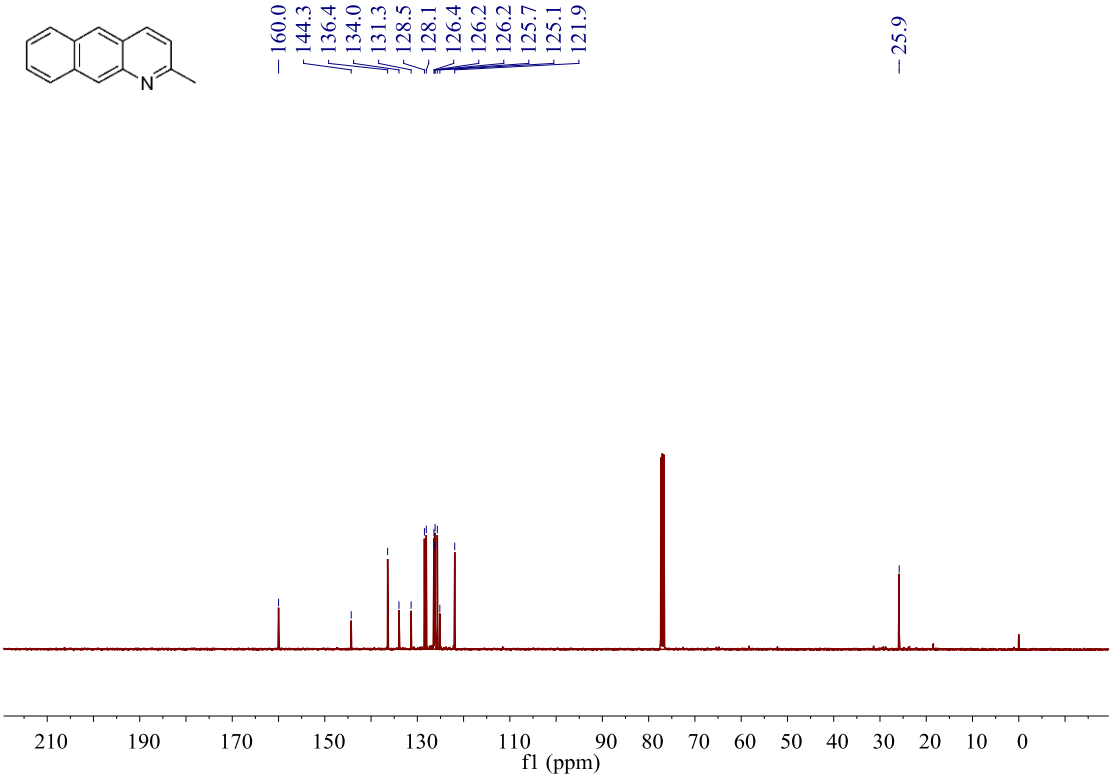

Figure S33. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3o**

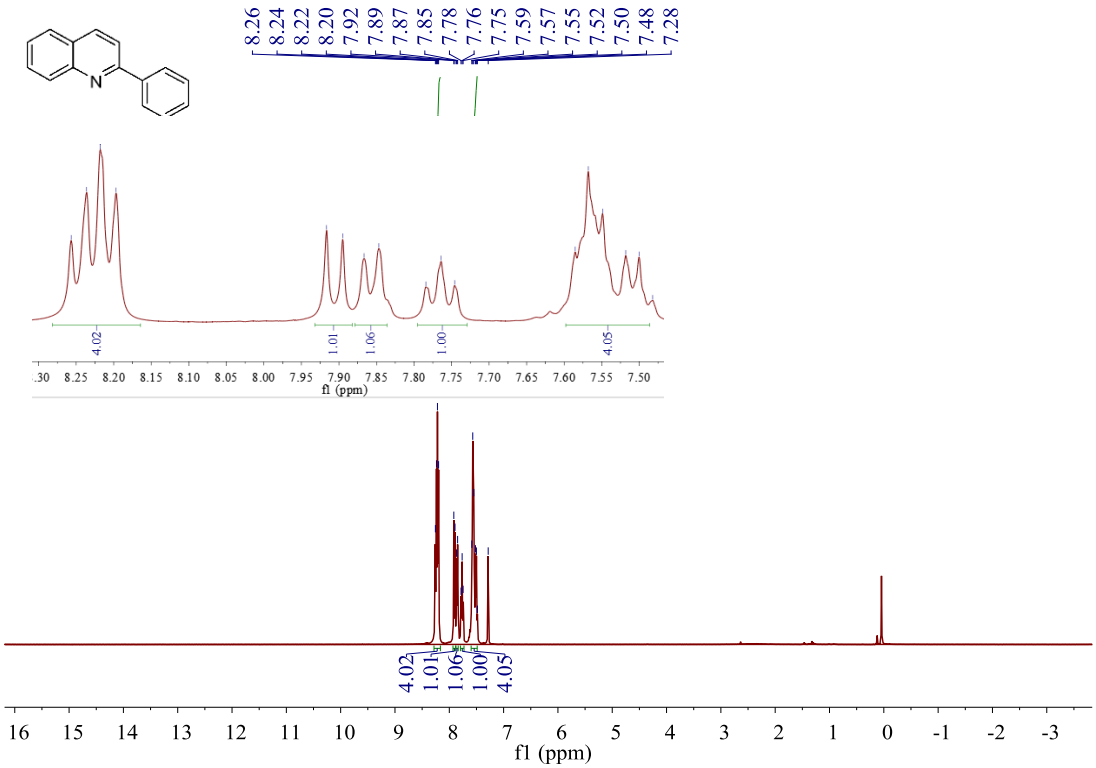

Figure S34. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **3o**

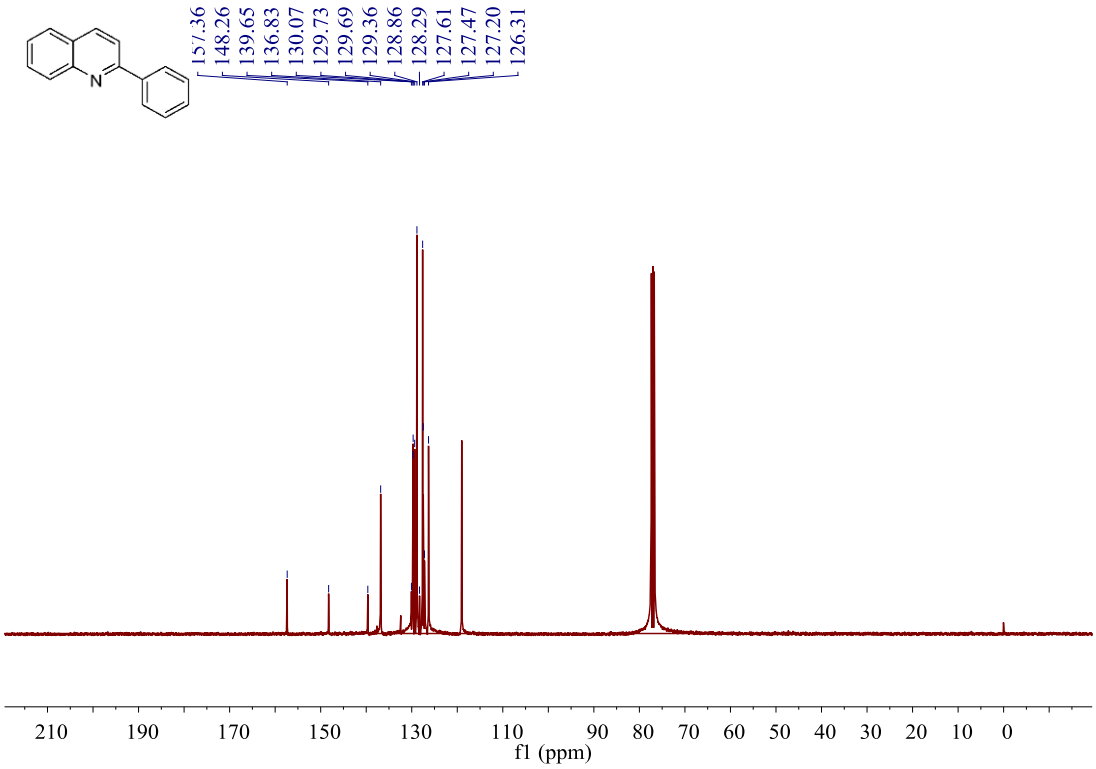

Figure S35. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3p**

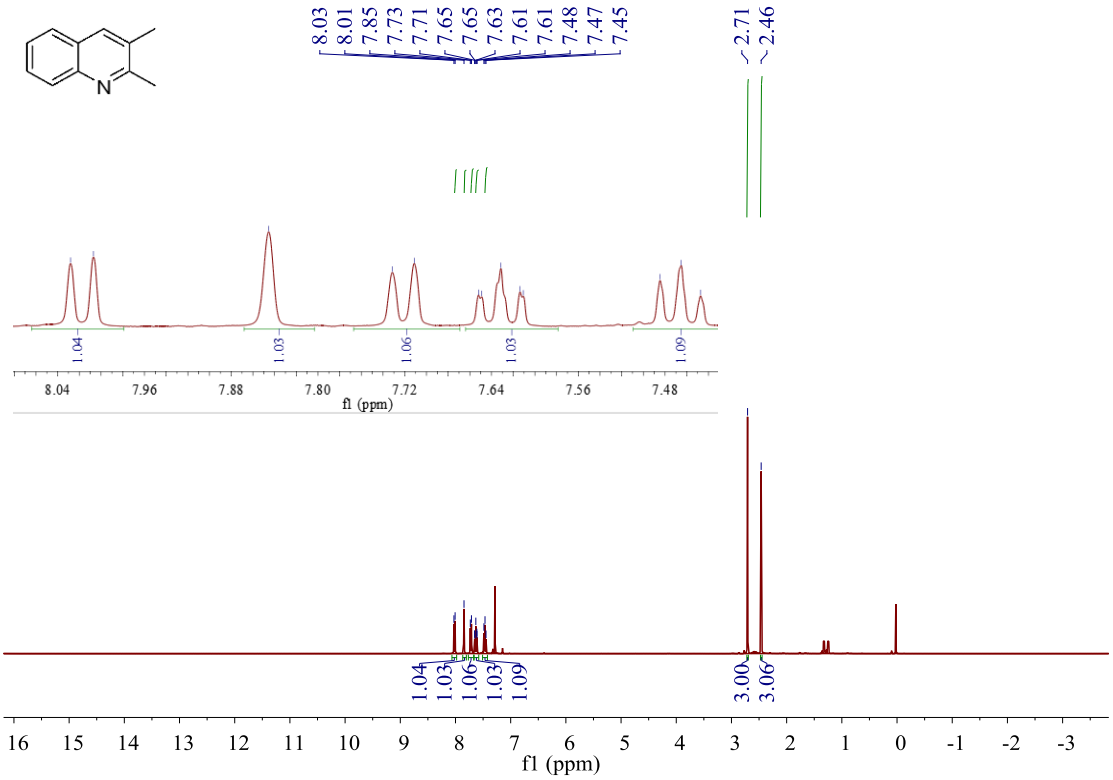

Figure S36. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **3p**

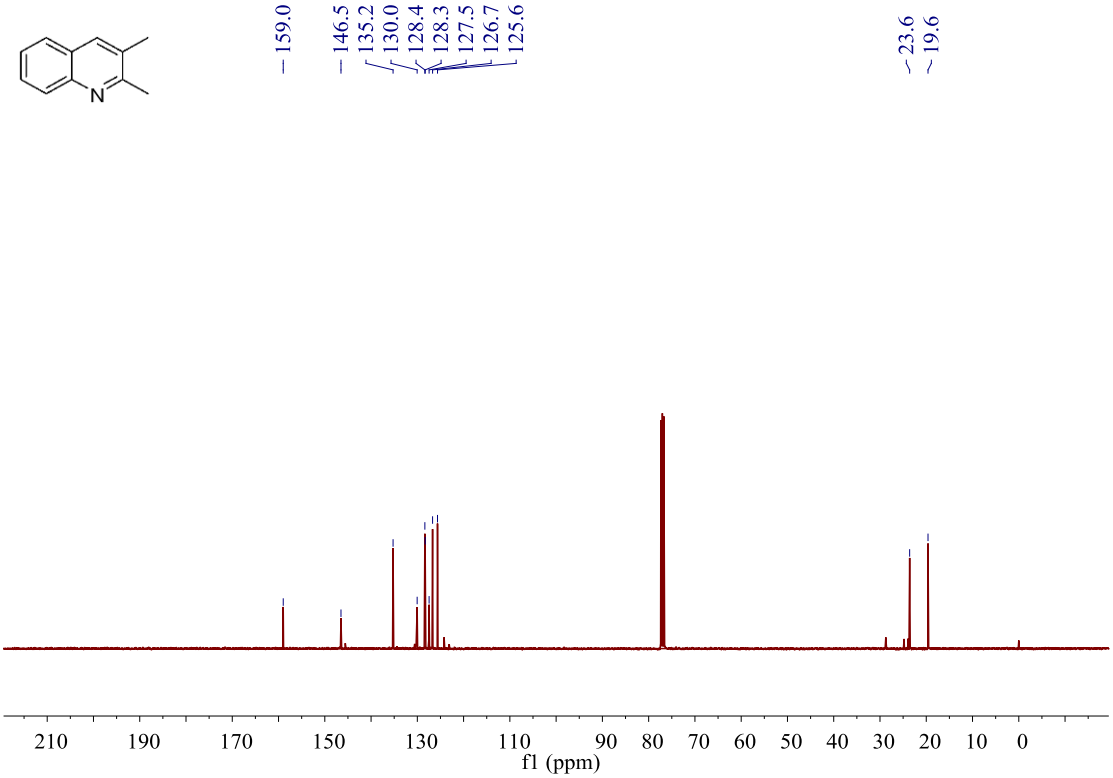

Figure S37. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3q**

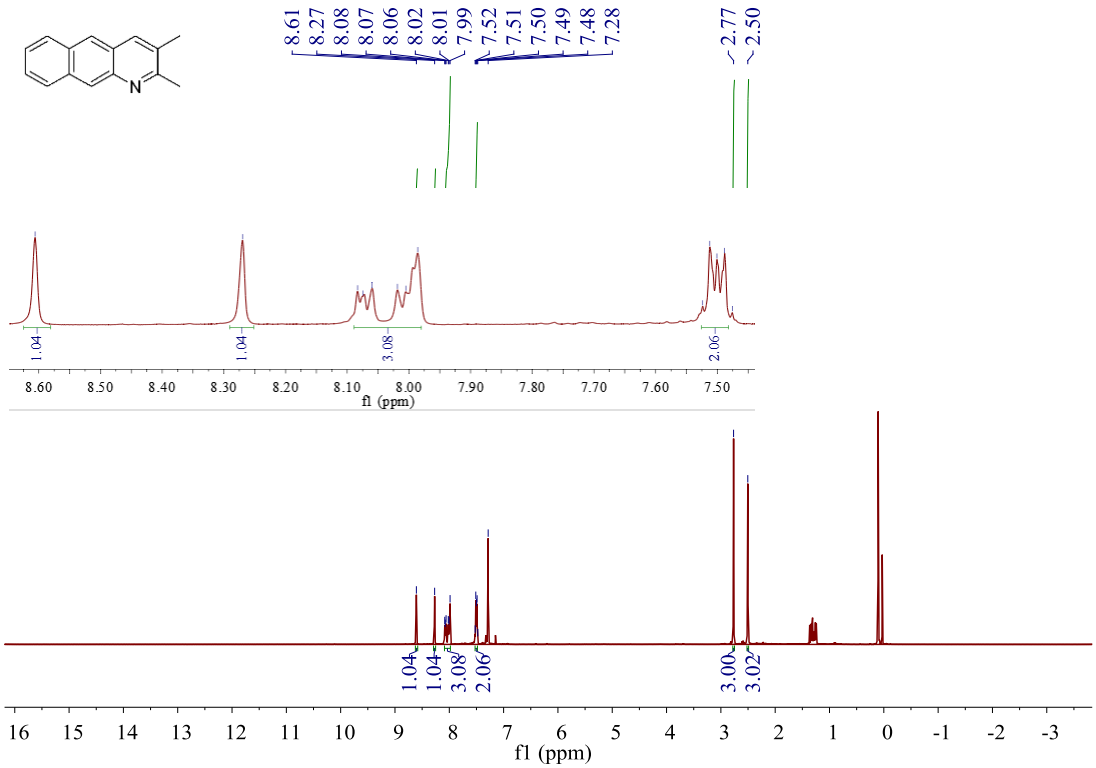

Figure S38. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **3q**

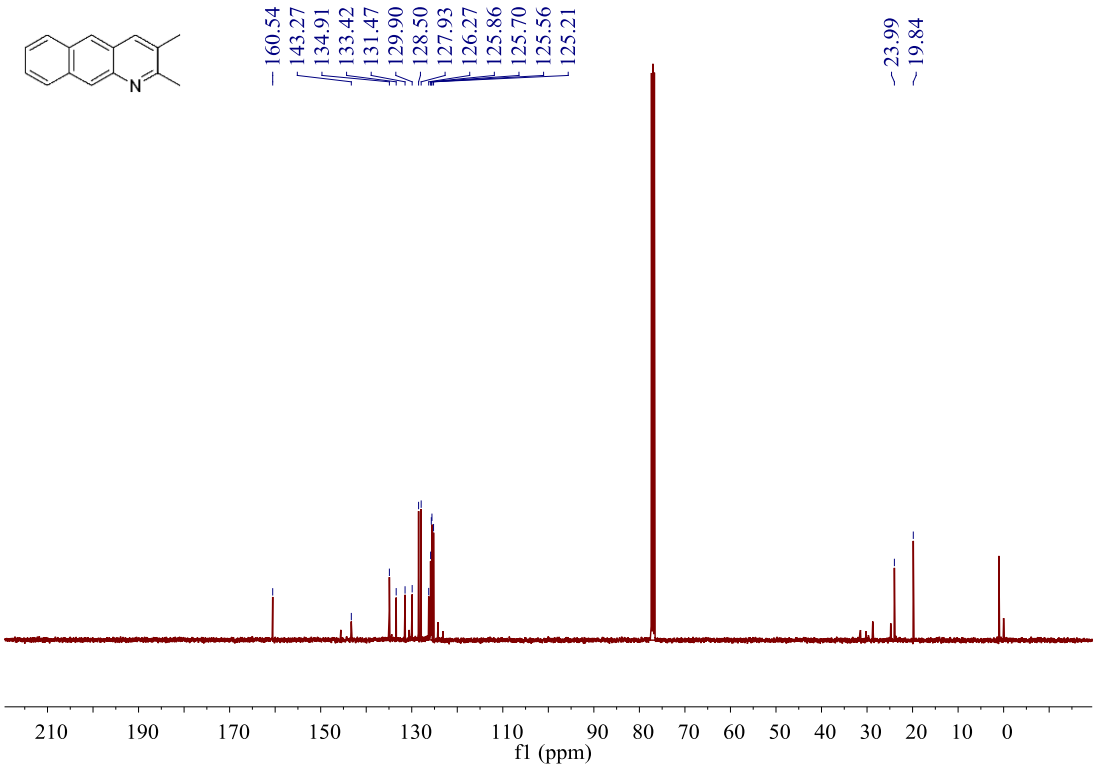

Figure S39. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3r**

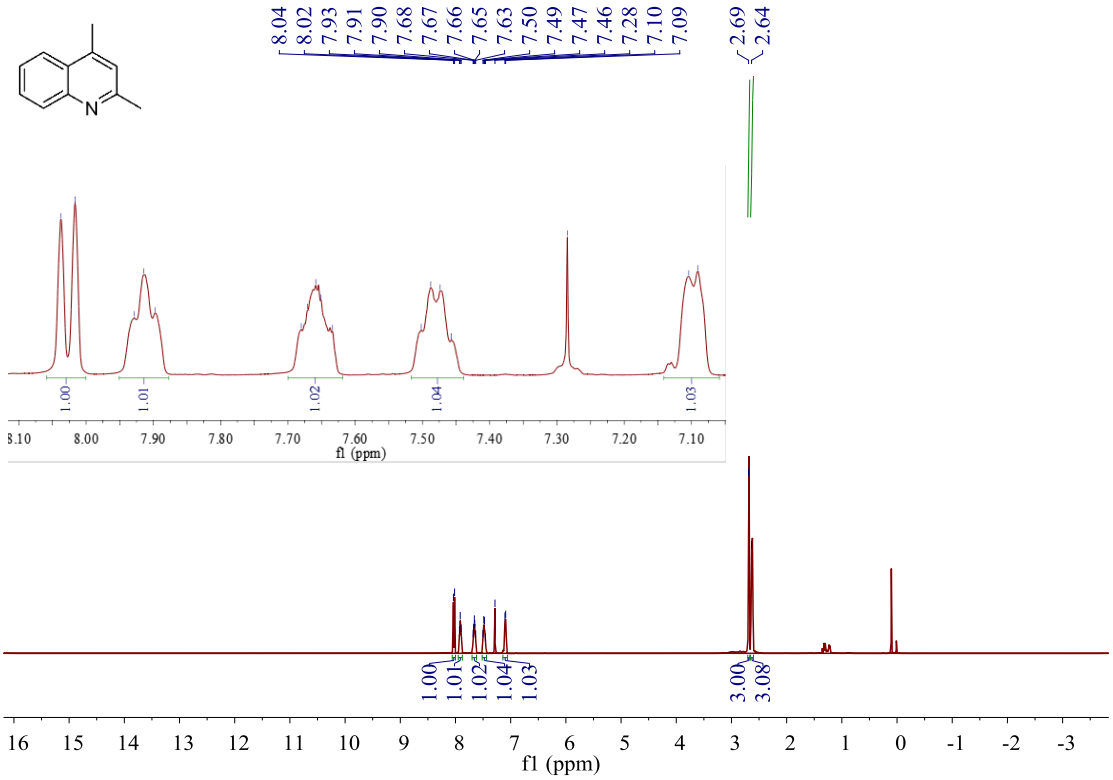

Figure S40. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **3r**

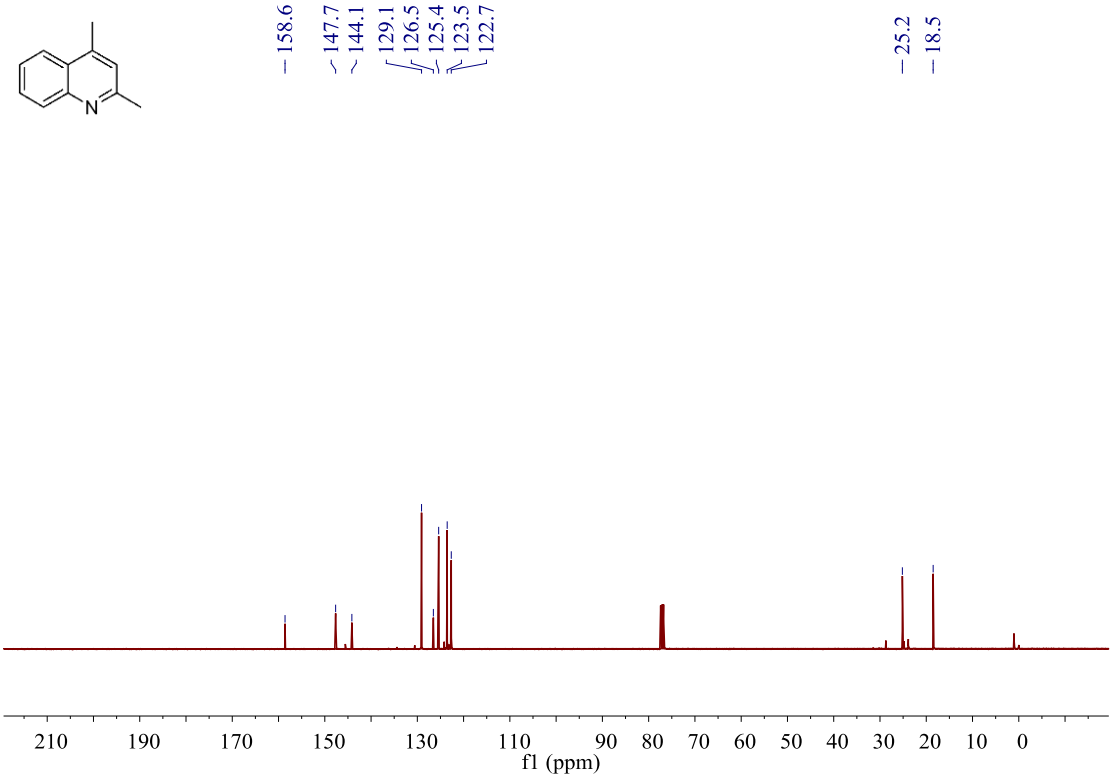

Figure S41. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3s**

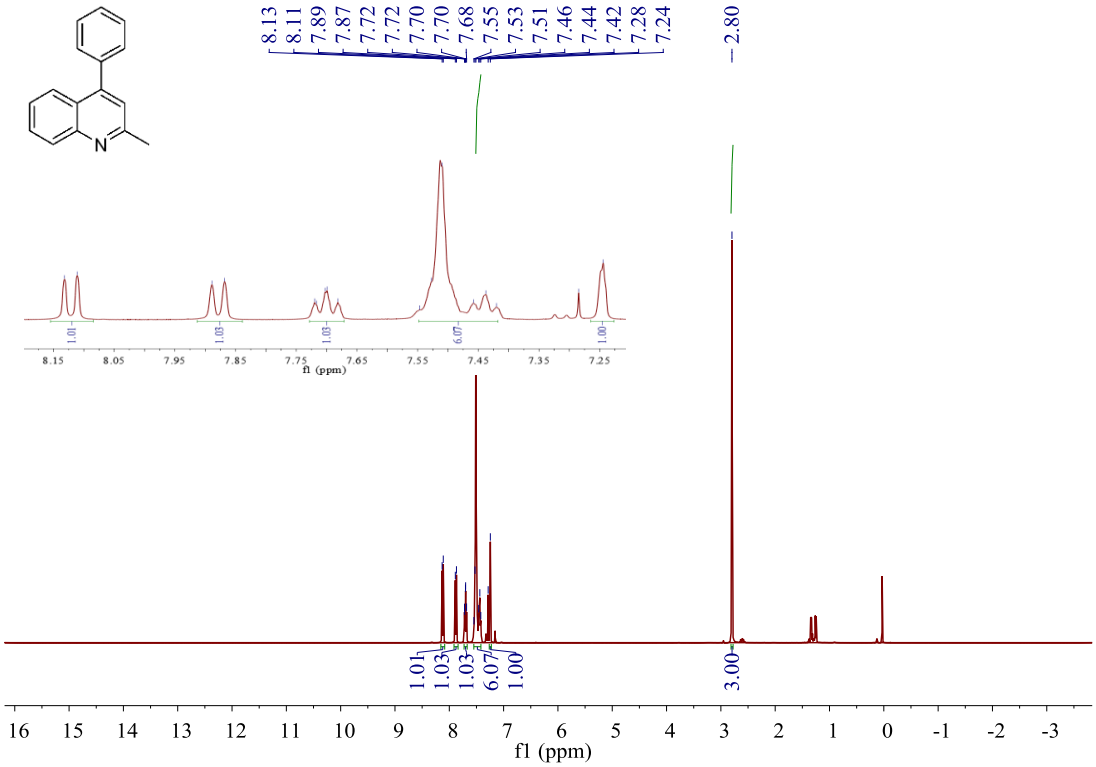

Figure S42. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **3s**

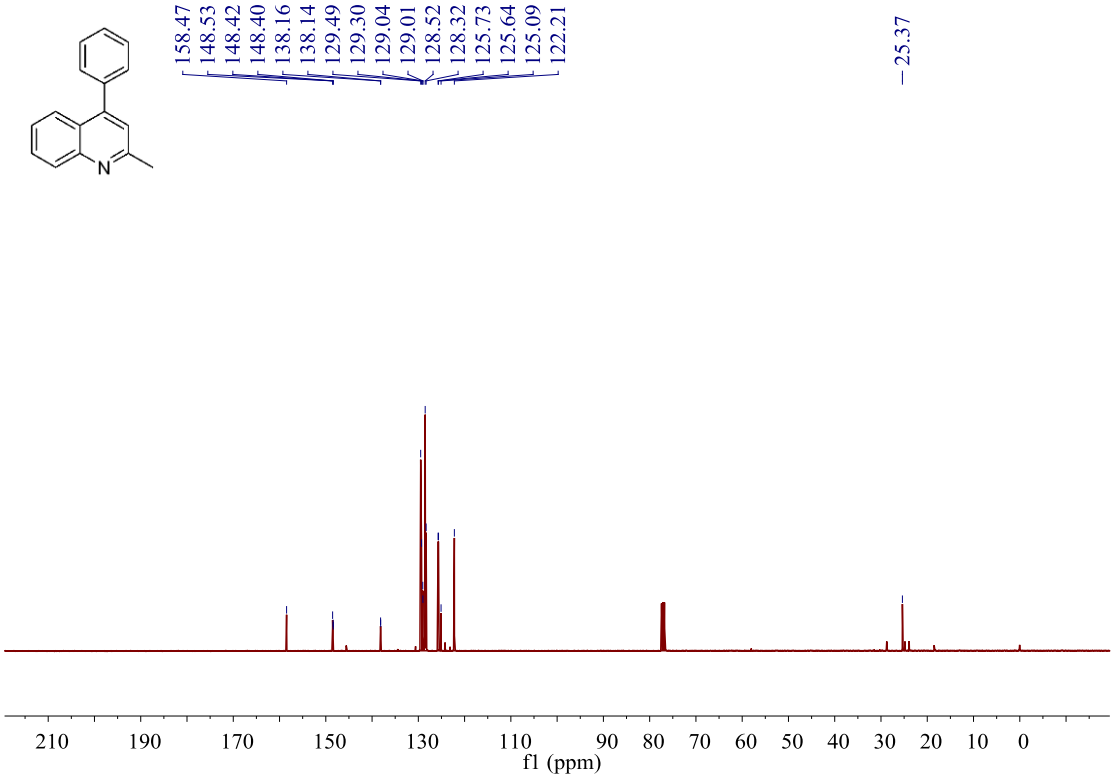

Figure S43. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **4a**

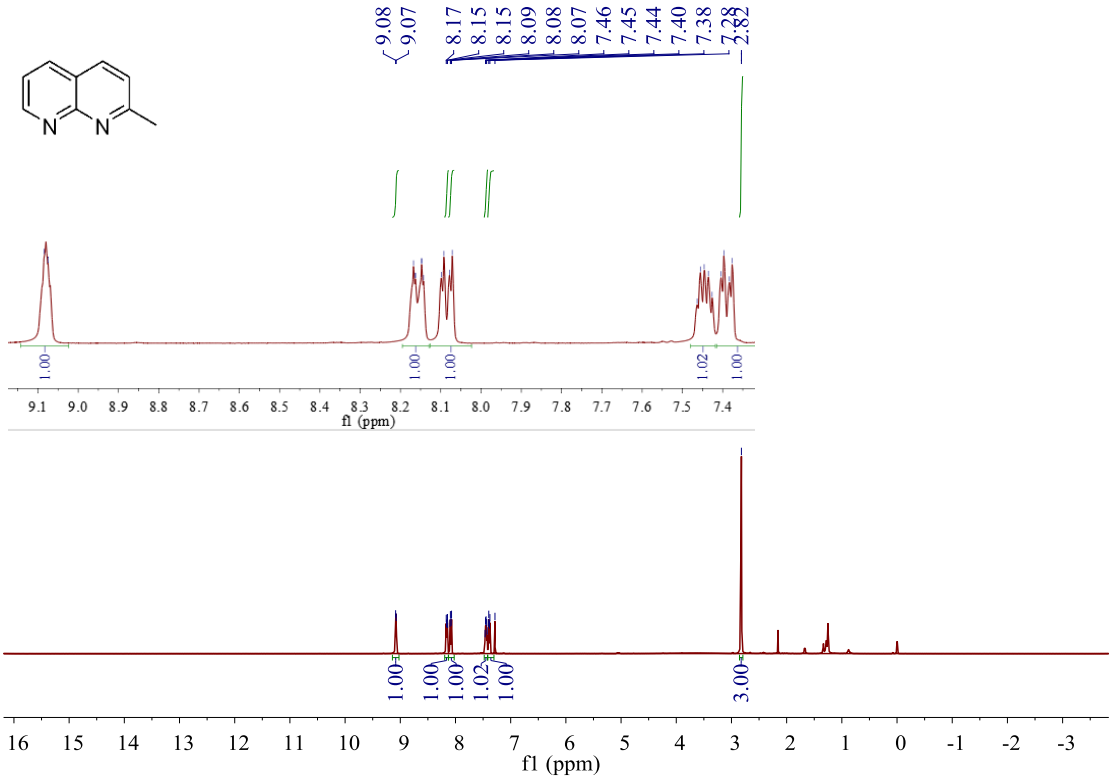

Figure S44. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **4a**

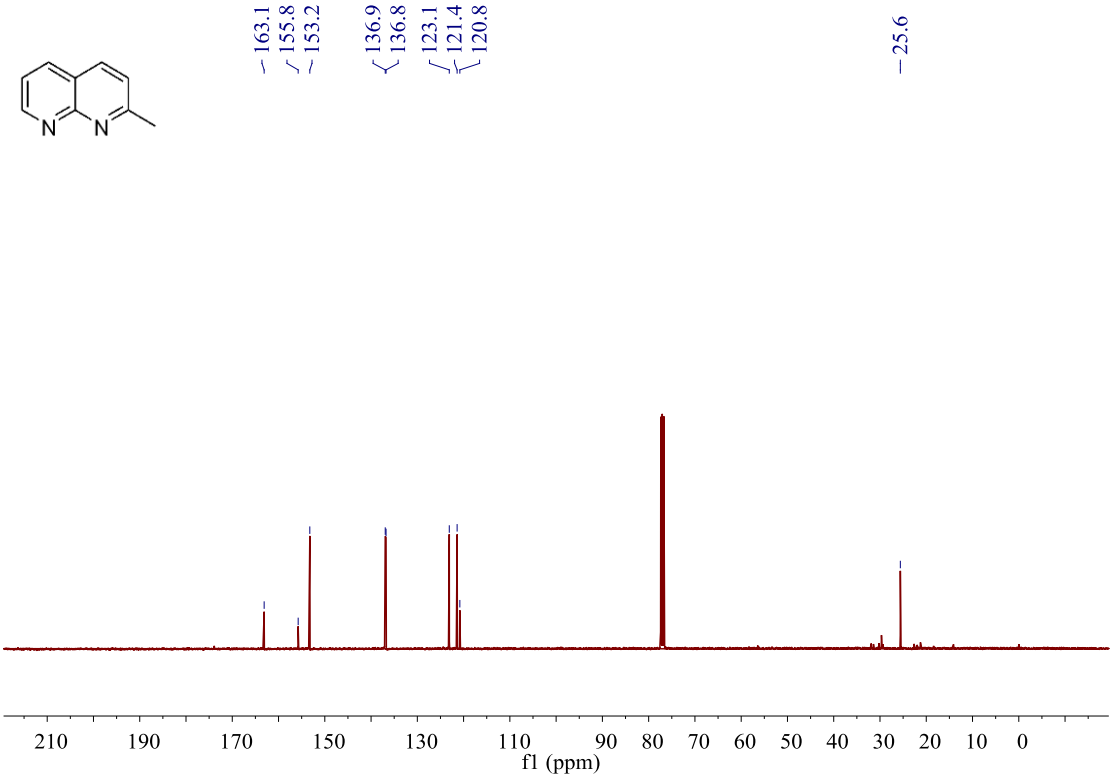

Figure S45. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **4b**

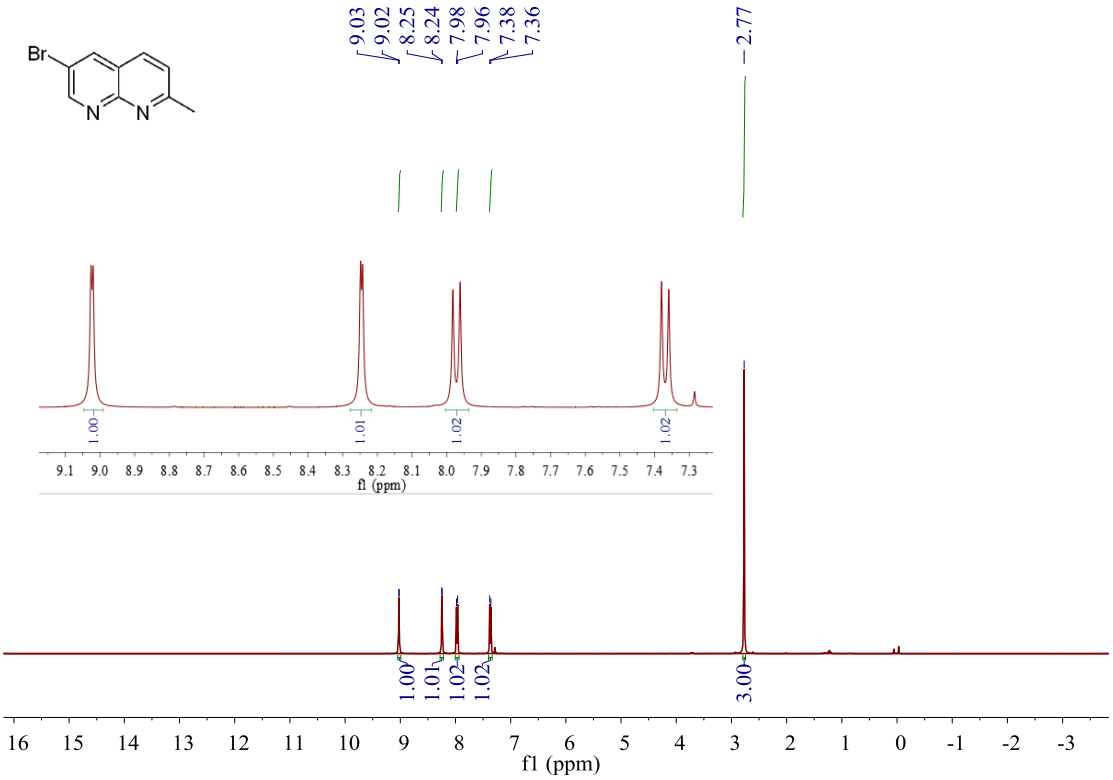

Figure S46 ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **4b**

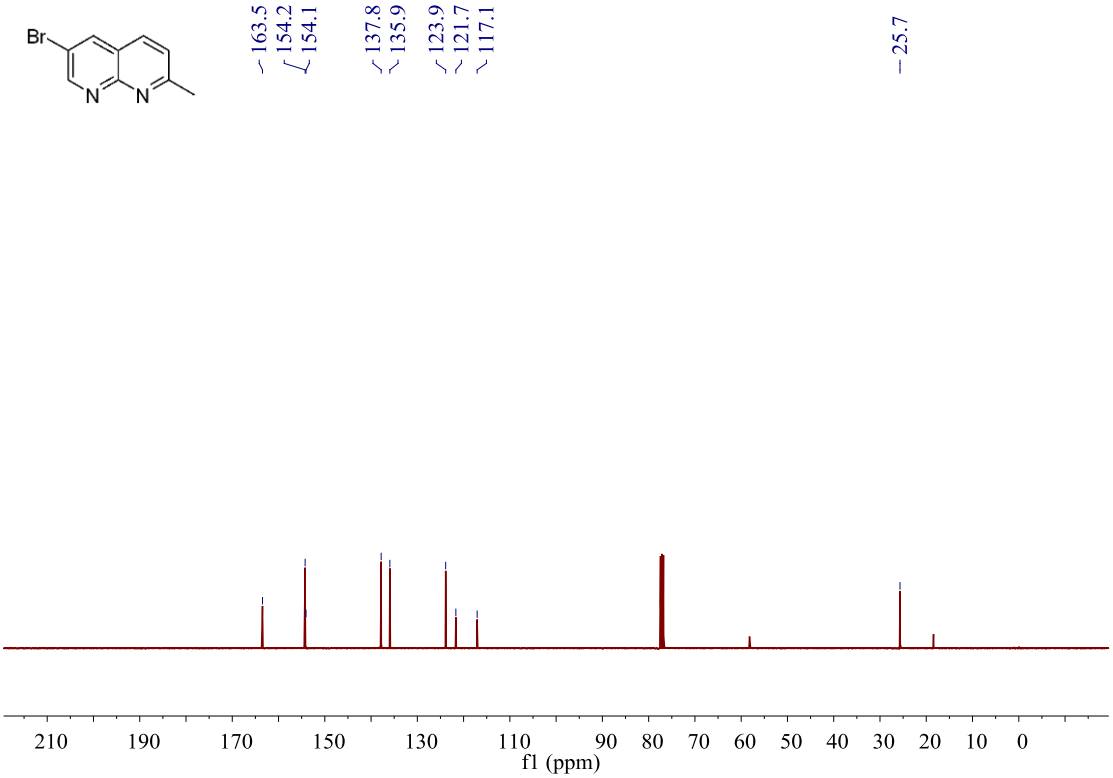

Figure S47. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **4c**

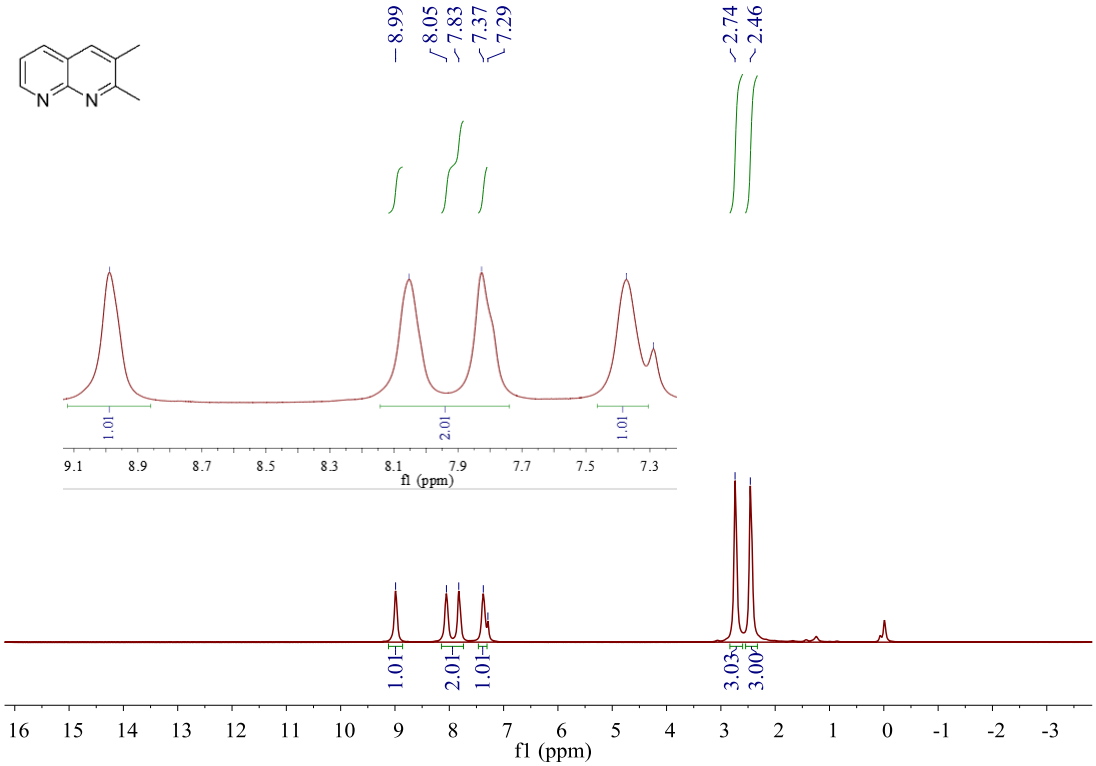

Figure S48. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **4c**

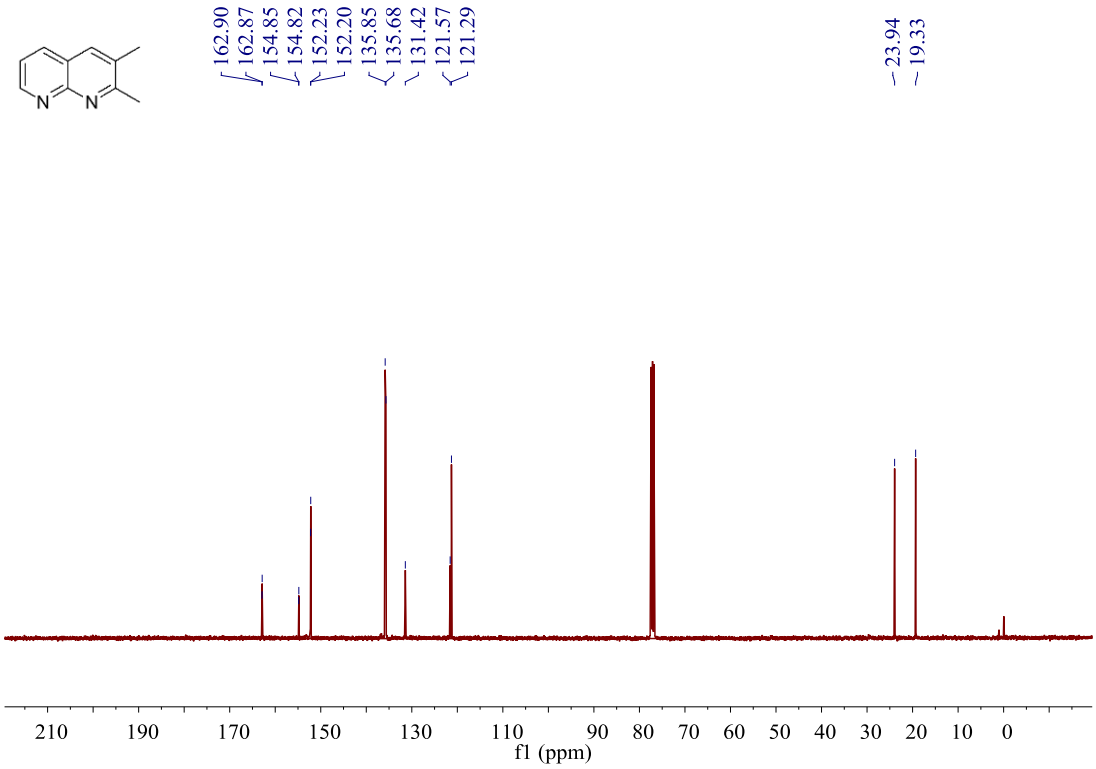

Figure S49. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **4d**

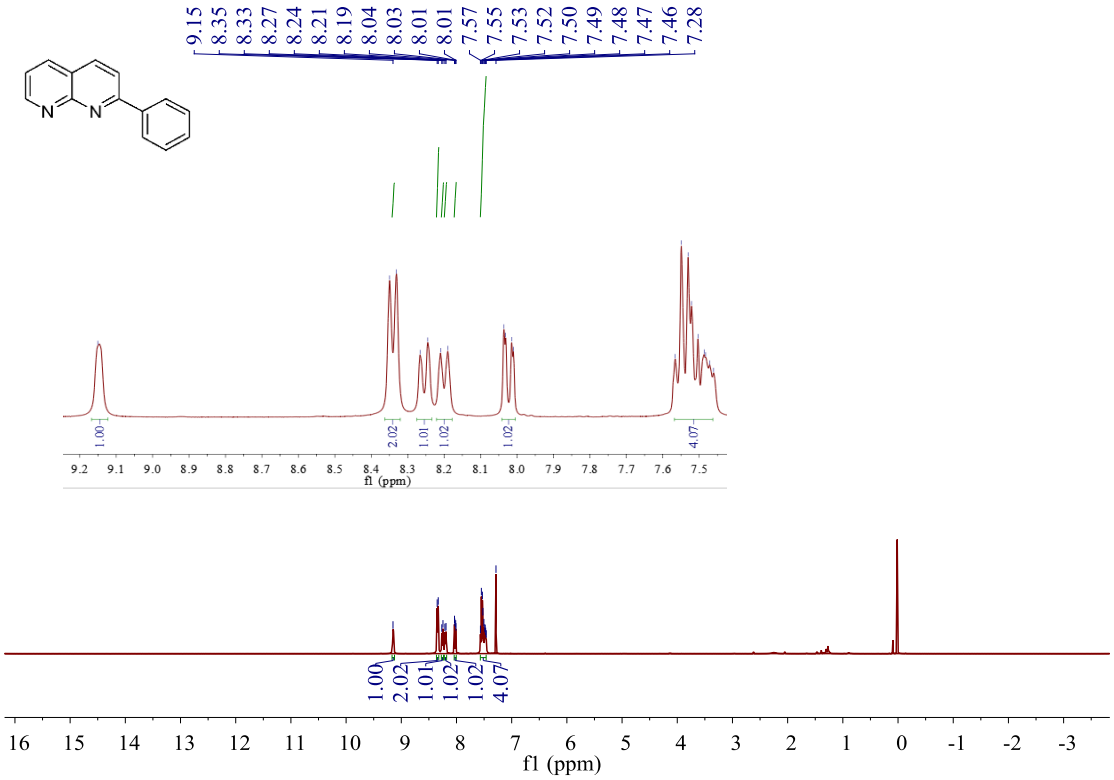

Figure S50. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **4d**

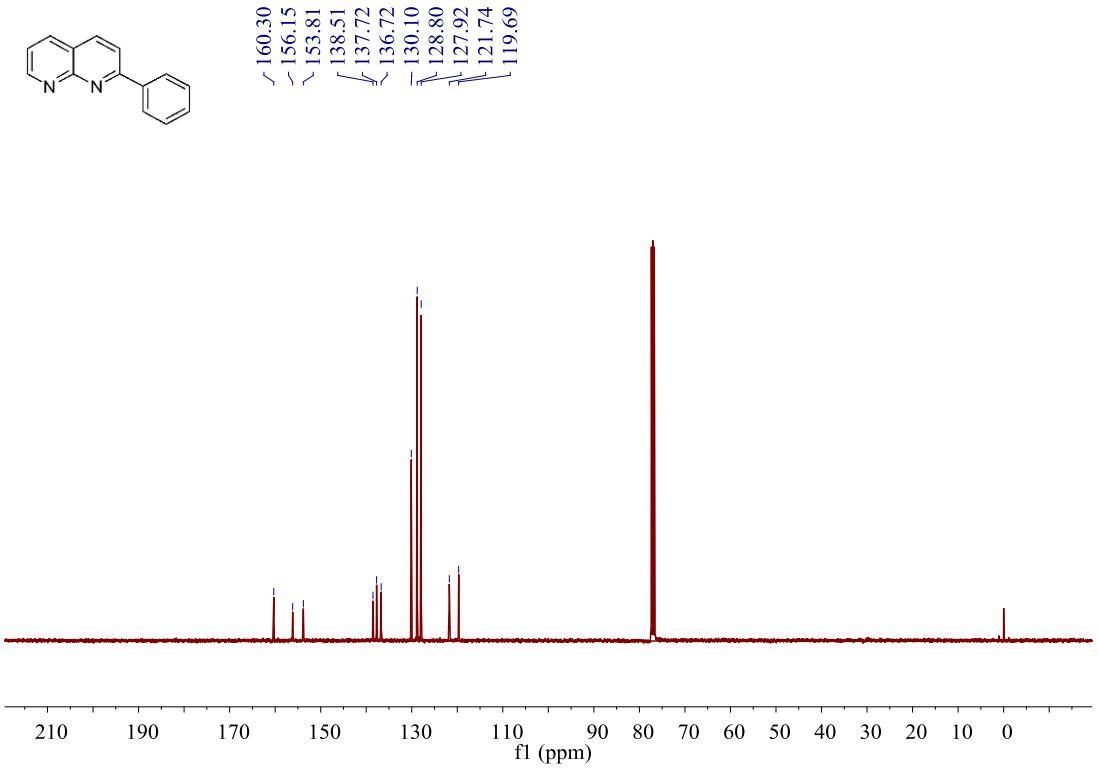

Figure S51. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **4e**

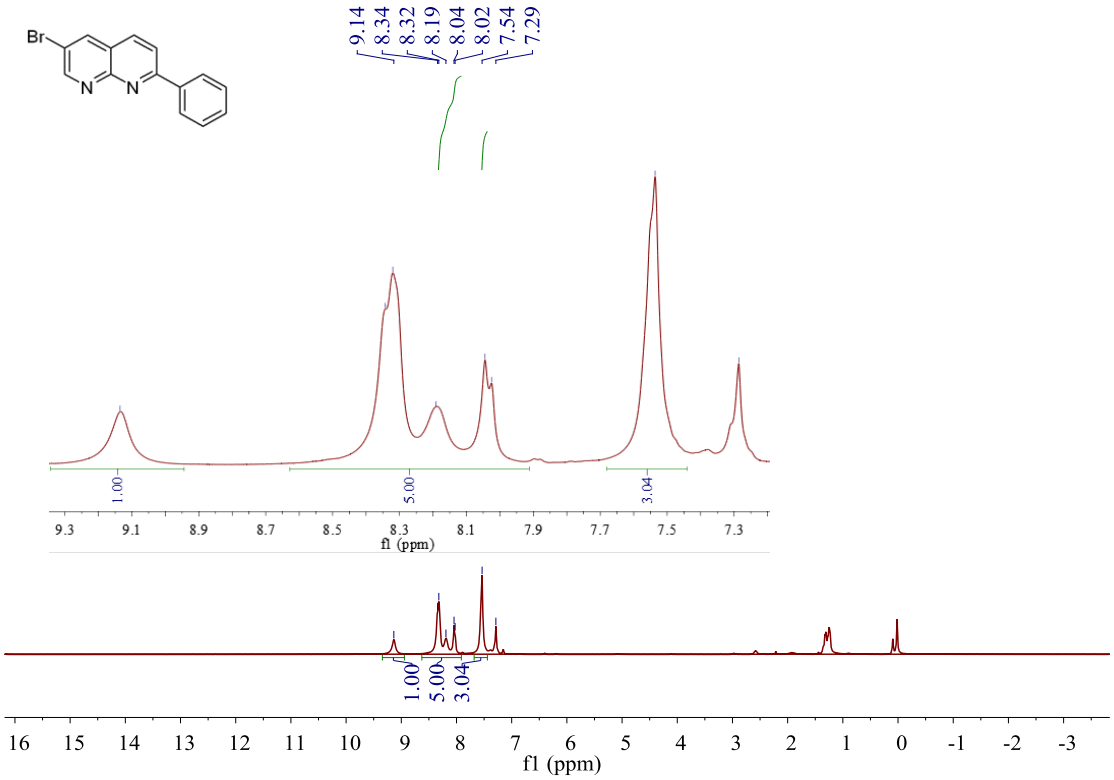

Figure S52. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **4e**

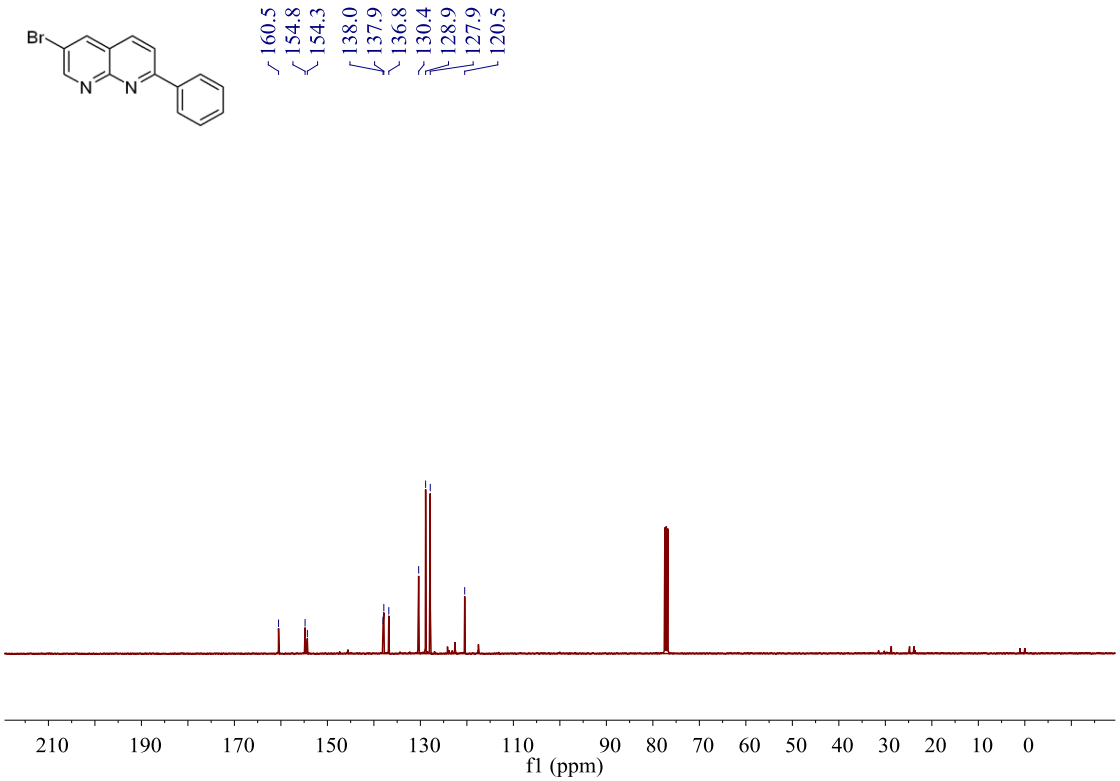

Figure S53. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **4f**

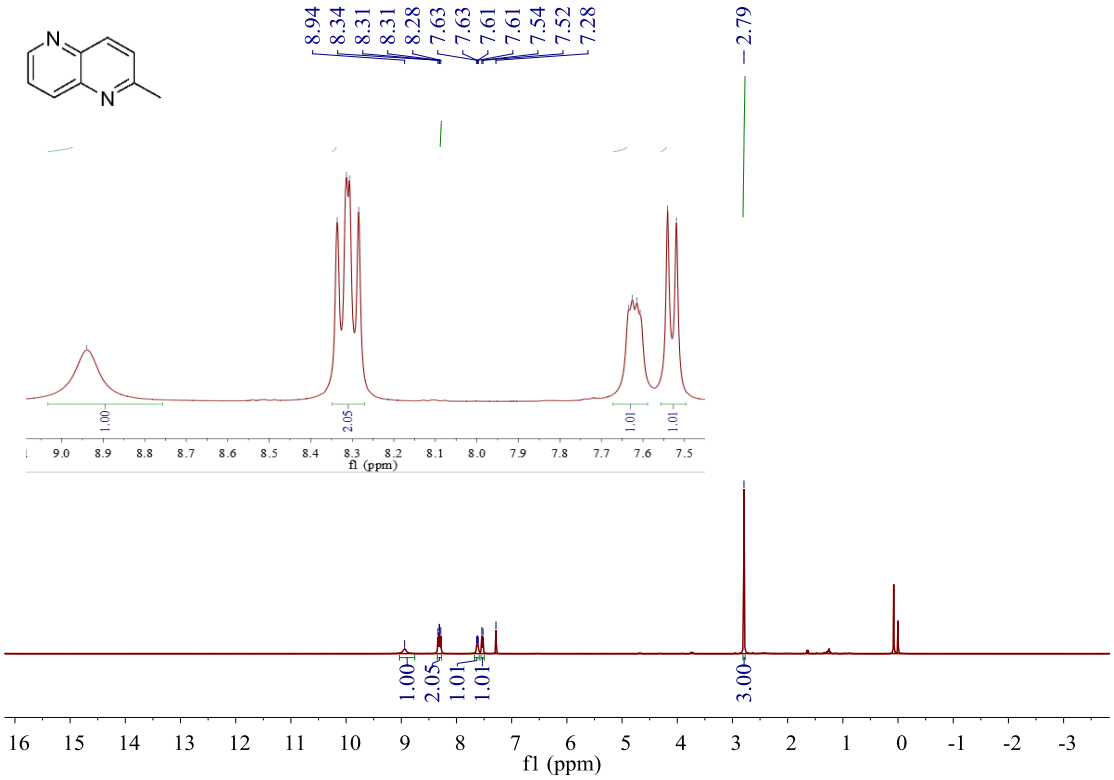

Figure S54. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **4f**

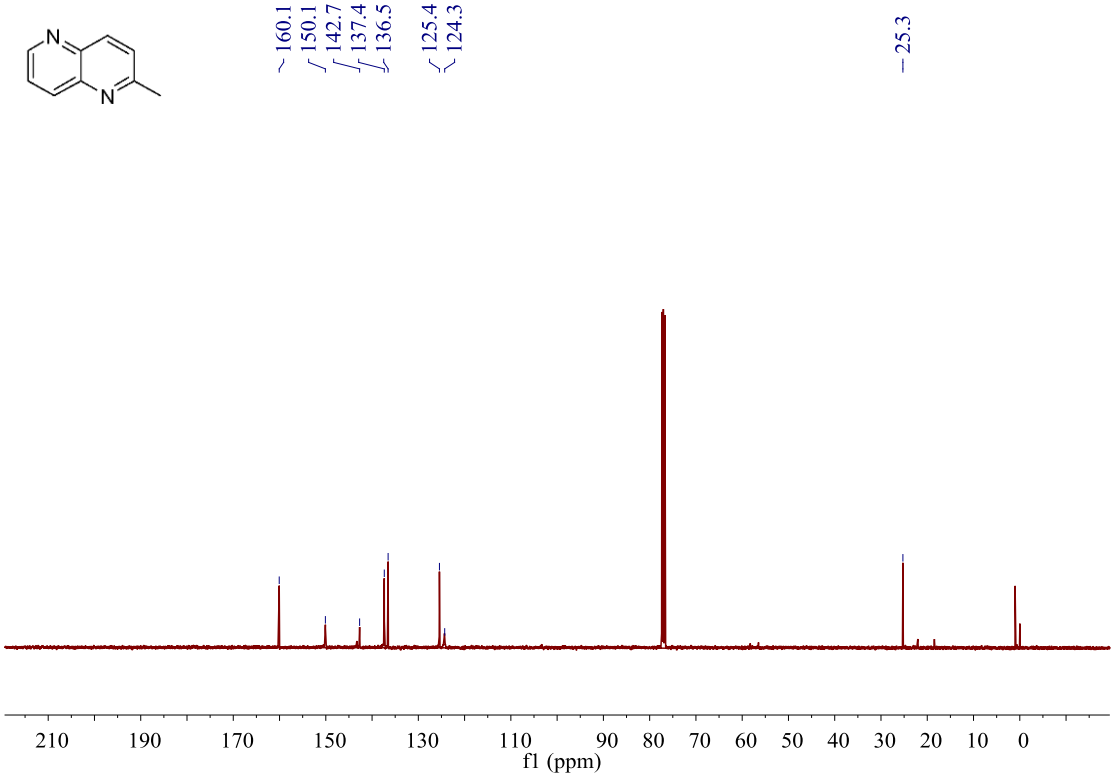

Figure S55. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **4g**

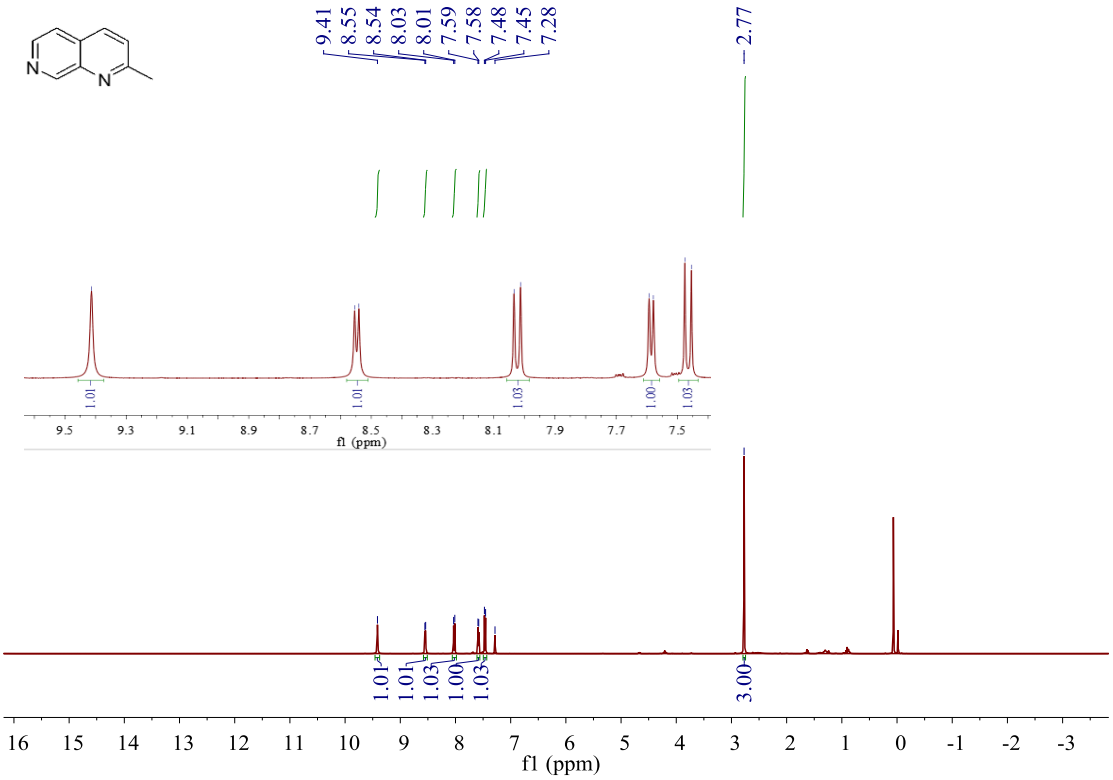

Figure S56. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **4g**

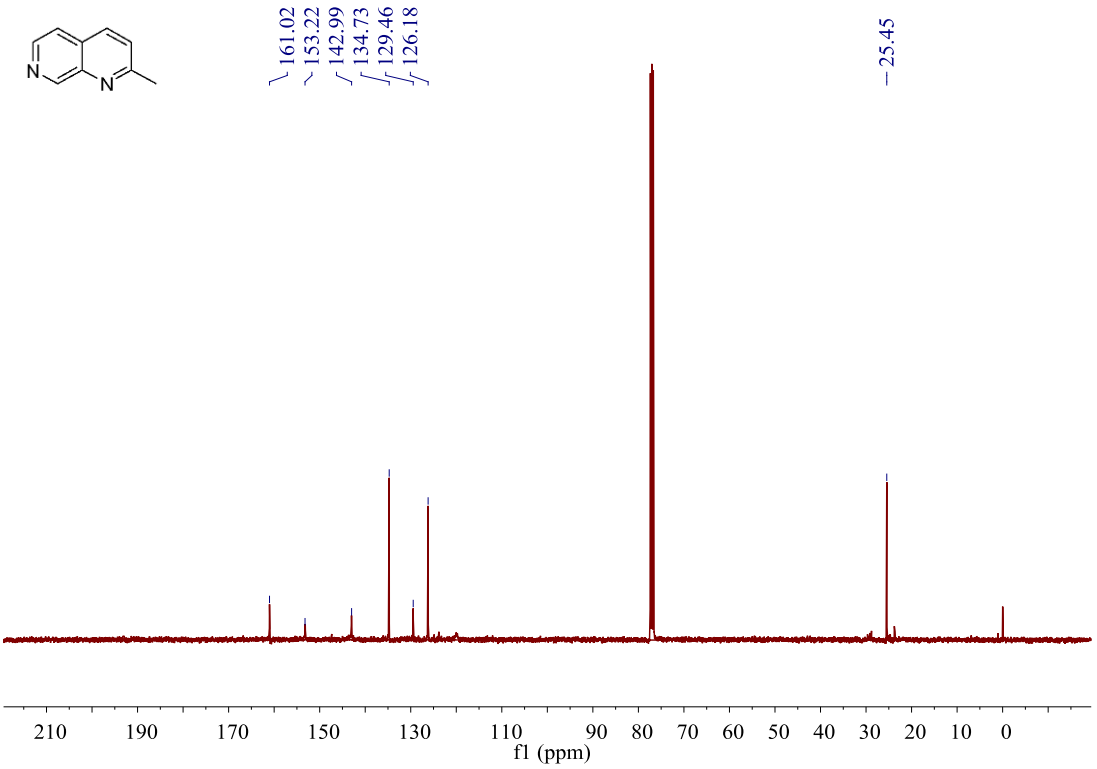

Figure S57. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **4h**

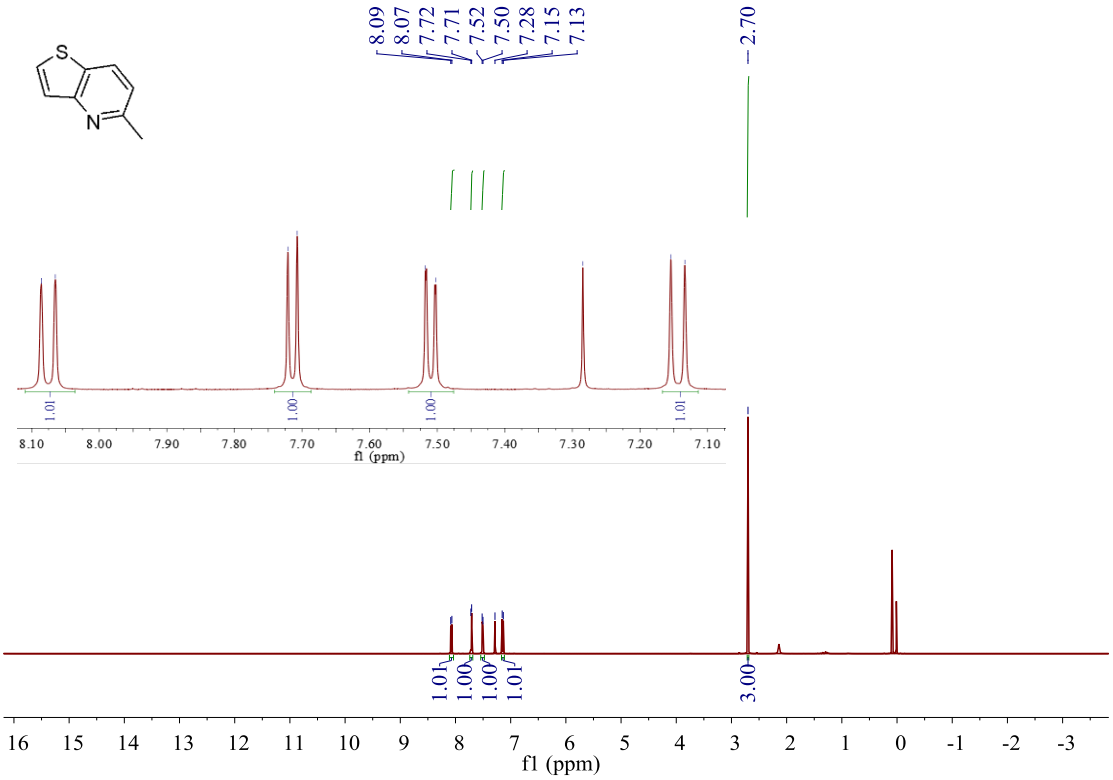

Figure S58. ^{13}C NMR (101 MHz, $CDCl_3$) spectrum of **4h**